

A Physiological Limits Database for Arctic and Subarctic Aquatic Species

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A Physiological Limits Database for Arctic and Subarctic Aquatic Species

by

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ABSTRACT

Steiner, N., Drost, H. E., Hunter, K. 2018. A Physiological Limits Database for Arctic and Subarctic Aquatic Species. Can. Tech. Rep. Fish. Aquat. Sci. 3256: v + 56 p.

The physical, chemical and biological properties of aquatic ecosystems in the Western Canadian Arctic and Subarctic are rapidly changing. The anthropogenic build-up of greenhouse gasses in the atmosphere and the consequent increase of ocean absorption of carbon dioxide (CO₂) are causing ocean warming and acidification respectively. We need to provide high resolution model projections for these aquatic ecosystems to help inform resource managers and subsistence harvesters about the potential impacts of climate change and ocean acidification.

Accurate projections with this level of complexity require linkages between high-resolution, basin-scale, ocean-ecosystem models and species-distribution models. To include multiple biological processes into these model platforms, the physiological limits and acclimation potential of key aquatic ectotherm species must be quantified. To address some of these needs we have created an ongoing Physiological Limits Database of Arctic/Subarctic species, which is based on published studies, fish catch data and Indigenous Knowledge reports.

RESUMÉ

Steiner, N., Drost, H., Hunter, K. 2017. Une base de données des limites physiologiques pour les espèces aquatiques Arctiques et Subarctiques. Can. Tech. Rep. Fish. Aquat. Sci. 3256: v + 56 p.

Les propriétés physiques, chimiques et biologiques des écosystèmes aquatiques des régions Canadiennes arctiques et subarctiques de l'Ouest sont en train de changer rapidement. L'accumulation anthropogénique de gaz à effet de serre dans l'atmosphère et l'accroissement résultant de l'absorption océanique de dioxyde de carbone sont les causes respectives du réchauffement des océans et de leur acidification. Il est nécessaire de fournir des projections de modèle à haute résolution pour ces écosystèmes aquatiques à fin d'informer les gestionnaires des ressources naturelles et les aquaculteurs de subsistance sur les impacts potentiels des changements climatiques et de l'acidification océanique.

Des projections précises à ce niveau de complexité requiert des connexions entre les modèles de distribution des espèces et les modèles océan-écosystème, avec une haute résolution et à l'échelle des bassins océaniques. Dans le but de reproduire de multiples processus biologiques dans ces modèles-plateformes, il est impératif de quantifier les limites physiologiques et le potentiel d'acclimation d'espèces aquatiques clés dites ectothermes. Pour répondre à certains de ces besoins nous avons créé une base de données des limites physiologiques des espèces arctiques et subarctiques continuellement mise à jour, laquelle s'appuie sur des publications d'études scientifiques, sur des données de prises de pêches et sur des rapports du Savoir Autochtone

1. INTRODUCTION

In 2017, the Arctic Monitoring and Assessment Programme (AMAP) published a report on Adaptation Actions in a Changing Arctic (AACA) in the Bering, Chukchi and Beaufort Sea stating that these regions are rapidly moving toward conditions never witnessed before based on scientific observations and traditional knowledge reports. Ocean changes such as warming, ocean acidification, sea-ice retreat and consequent habitat loss creates multiple stressors on Arctic and Subarctic marine ecosystems. For instance, increasing water temperature and the loss of sea-ice quality and quantity have led to changes in the distribution and composition of algae, zooplankton, fish, marine mammals and birds (e.g., Grebmeier and Maslowski, 2014, Steiner et al., 2015, AMAP, 2017). Coastal communities are impacted as subsistence species decline or move beyond the geographic reach of harvesters. Additional access complications are linked to changes in weather, storms and sea state (see review by Steiner et al., 2015), which have made the sea rougher, less predictable and more dangerous for small boat travel, according to local Inuit (Carmack & Macdonald, 2008; Pearce et al., 2011; Clarke et al., 2015; Stern et al., 2015; Inuvialuit Game Council members, pers. comm.). AMAP (2017) suggested that restructuring indigenous harvesting practices in response to changes in the species composition and availability of subsistence food resources might be inevitable.

The weakest link in determining ecosystem risks and fisheries impacts of climate change (e.g. increased temperature, sea-ice/habitat loss), ocean acidification, noise and pollution is the lack of information on physiological limits of key Arctic marine species to single and multiple stressors (Werner et al., 2007, Allen et al., 2011, Steiner et al., 2016). This critical insufficiency has been identified as an important factor of uncertainty in food-web and species-distribution models (AMAP: Arctic Ocean Acidification Assessments, submitted 2018). Projected changes to biologically-important physical properties of Canada's coastal areas may change habitat suitability for fish and invertebrate species. How species will potentially be impacted requires greater understanding of physiological tolerances to ocean parameters such as temperature, pH, salinity and oxygen levels. There is limited understanding of the impacts of ocean climate parameters, acting individually or in synergy, on these cold-dominated areas.

Our primary objective in this study is to collate knowledge of species responses to single and multiple stressors into an Aquatic Species Physiological Limits (ASPL) database, which will be updated over time. In this report we synthesize information on tolerances, thresholds and acclimation potential to climate change and ocean acidification stressors for Arctic and Subarctic marine species. The information is compiled in MS Access database format with the ability to include updates as they become available using an input form that is linked to the master database. The data includes thresholds (optimal, sub-optimum and lethal limits) and acclimation potential estimates for key Arctic/Subarctic aquatic ectotherm species. The estimates focus on the potential to acclimate to increasing temperatures, which is a primary driver of species distribution. It is important to note that: (1) temperature thresholds and limits may vary with life stage, (2) different life stages may occupy different depth levels at different times of the year, which makes them more or less sensitive to environmental changes, and (3) this initial version of the ASPL database is focused on marine fish and zooplankton found in the

Inuvialuit Settlement Region (ISR) of the Canadian Arctic. However, the database structure does not limit location or species. In addition to summarizing the available species information, the ASPL database identifies commonalities among species and existing data gaps. The key Arctic marine forage fish Arctic cod (*Boreogadus saida*) is highlighted as an example species in this report.

Compiling physiological limits to climate change multi-stressors will improve our ability to link climate models with higher-trophic-level models, which is required to properly assess impacts on selected Arctic fish species and potential subsistence/commercial fisheries. To include multiple biological processes into species distribution models, our knowledge base of species responses, thresholds and acclimation potential needs to be developed and expanded.

Current ecosystem models have significant data gaps, tend to use simple temperature-dependent growth formulations and are constrained to mostly constant mortality rates to express characteristics of food-webs/bioenergetics (i.e. plankton growth). These models cannot predict the response and adaptation of whole ecosystems to multiple stressors and they offer limited predictive power regarding the response or acclimation potential of individual species to the expected long-term change in any climate related variable. Equally limited, species distribution models often lack historical species data to reproduce species shifts and extinction and do not include species responses such as changes in performance, metabolic rates, fecundity, behaviour and acclimation.

To initiate this complex analytical approach, two coastal marine ecosystems were selected for high-resolution model analysis in the Inuvialuit Settlement Region (ISR) in the Western Canadian Arctic. Initial literature search results highlight: (1) a significant knowledge gap on single and especially multi-stressor impacts on species physiology and (2) the importance of matching life stages with habitat (location and depth) to identify ecologically relevant physiological limits. We encourage further extension of this ASPL database via continued literature research, dedicated laboratory experiments to fill knowledge gaps as well as by long term pan-Arctic/Subarctic coastal and offshore monitoring of key aquatic species and their rapidly changing habitats.

2. BACKGROUND AND METHODS

2.1 Eco-physiology

Eco-physiology is the scientific exploration of the inter-relationships between the physiology of organisms and their environment. One component of eco-physiology is to understand the impact of climate change on key marine food-web species. Arctic marine species are experiencing a multi-stressor environment with potential synergistic effects, but few laboratory studies have examined these compound impacts.

For marine ectotherm species (cold-blooded animals whose body temperature follows that of the surrounding environment), temperature limits can be quantified by measuring physiological rates such as growth rate, heart rate, oxygen uptake and rate of mitochondrial leaking. In fact most physiological rate functions can be used to quantify temperature and other stressor limits. However, heart rate and oxygen uptake data are included in the ASPL database (see Section 2.2 for details) as they are highly reproducible methods with good resolution and have gained traction in recent years

(Farrell et al., 2008, 2016; Anttila et al., 2013; Ferreira et al., 2014; Drost et al., 2016). These rate measurements can pinpoint subtle performance decline during acute temperature tests that can be categorized as: sub-optimal (or T_{pejus} “getting worse”), optimal, (T_{opt}), maximum (T_{max}), and critical (T_{cmax} or T_{cmin}) temperatures and can be measured confidently to 0.1°C (e.g. Drost et al., 2014).

Pörtner and Farrell (2008) suggest that animals, including marine species, perform best within a window of optimal temperatures wherein absolute aerobic scope is at maximum. Absolute Aerobic scope (AAS) defines the capacity to deliver additional oxygen to support specific activities beyond basic needs (Fry, 1947; Farrell, 2016). Oxygen demand for activities such as digestion, feeding, growth, reproduction, locomotion, immune competence, predator avoidance can influence species distribution and ultimately survival (Fry, 1947; Pörtner and Knust, 2007; Pörtner and Farrell, 2008; Franklin et al., 2013). Changes in AAS, and consequently performance, under stress can affect animal health. The upper and lower pejus temperatures (T_{pej}) are often set at 90% of peak aerobic scope and could influence species distribution and even survival (Pörtner et al., 2008; Eliason et al., 2013; Farrell, 2016). While acclimation might allow this window to shift (as shown by Ferreira et al., 2014; Drost et al. 2016), additional stressors may shrink the thermal window and hence limit the thermal range of optimal performance (Pörtner and Farrell, 2008). Quantifying species tolerance to climate change multi-stressors can be accomplished by measuring absolute aerobic scope and other fundamental physiological responses.

Stressor-related change in heart rate is another reliable indicator of animal health and performance (Randal and Shelton, 1963; Brett, 1979; Armstrong 1986; Casselman et al., 2012). Laboratory multiple-stress tests, based on quantifying the change in cardio-respiratory performance, can allow for the detection of sub-optimal “pejus” levels of stress. Sub-optimal “pejus” temperatures are potentially more ecologically significant than a species critical temperature maximum (Drost et al., 2016). Health can also be assessed by quantifying change in genetic regulation and fatty-acid and stable-isotope profiles based on acclimation conditions. These methods can also address broader questions such as energetics and potential changes in food-web dynamics (Budge et al., 2008; Graham et al., 2014; Kohlbach et al., 2017).

2.2 Key Arctic and Subarctic Climate-Ocean Stressors

2.2.1 Ocean Warming

Many physical and chemical changes are occurring faster and are more profound in the Arctic than in any other region of the world. A recent assessment for the Canadian Arctic (Steiner et al. 2013, 2015) indicates that air temperature over Arctic land areas has increased during the last 30 – 50 years by 0.3 – 0.5°C/decade. Huang et al. (2017) state that revised estimates of Arctic surface air temperatures (SAT) now indicate that from 1998 – 2012 the mean annual increase was six times the global average. Over the Arctic Ocean SAT data are sparse and thus 50 year projections have a range in values, but they are increasing in summer and winter months by 0 – 3°C and 3 – 7 °C respectively. So far only a weak ocean surface warming has been observed, but summertime increases of 0 – 2°C are projected over the next 50 years (IPCC, 2014).

2.2.2 Changes in Sea-ice Cover, Stratification and Impacts on lower trophic levels

As indicated in Steiner et al. (2013, 2015), the Arctic-wide decrease in the extent of multi-year ice during the last 20 years has become evident in the Canadian Arctic during the last decade. The expanse of ice-free water in late summer has increased correspondingly. The average age of remaining multi-year ice has decreased and its average thickness is less. First-year ice is forming later in autumn in most areas and is dissipating earlier in summer. However, available data do not reveal any clear changes in the thickness of first-year ice throughout the Canadian Arctic, either in the land-fast or pack-ice domains. Over the next 50 years mean sea-ice thickness is suggested to continue decreasing by 0.25 – 1.75 m with further decline in multi-year ice area, possibly enabling an ice-free Arctic in late summer (Steiner et al., 2015; IPCC, 2014). The decrease in summer ice extent by 10 – 80%, depending on the area, will be accompanied by longer open water seasons with earlier ice break-up and later freeze-up. Model projections suggest little change in winter ice conditions.

With respect to stratification, the temporal and spatial coverage of data are insufficient to delineate trends across the Canadian Arctic. However, we do know that sea-ice melt, increased precipitation and river inflow enhance stratification in some areas. Model projections suggest a likely strengthening of stratification with mixed layer depth decreasing by 1.5 m, as a basin average maximum estimate, and up to 10 – 40 m in the central Beaufort Sea. This is. Enhanced stratification is associated with a decrease in upper ocean nutrients, which directly impacts primary production.

Current Earth system models do not agree on what drives primary production. Some indicate that a decrease in available nutrients, due to increased stratification, drives productivity down and favours smaller species assemblages (Li et al., 2009; Lee et al., 2013; Yun et al., 2014). Others show that increased light availability, due to a reduced sea-ice cover, is the driver of primary production (Vancoppenolle et al., 2013). There are significant correlations between the timing and variability of sea-ice retreat and pelagic production (Ji et al., 2013; Brown and Arrigo, 2013; Fujiwara et al., 2014), and there are studies that indicate a more subtle interplay between reduced ice and nutrient upwelling driving primary production. Changes in irradiance transmitted through snow and sea-ice also directly influence the production of sea ice algae (Arrigo, 2014; Leu et al., 2015), including timing, quantity and quality of algal biomass and the development of under-ice blooms (Arrigo et al., 2012). For instance, Ardyna et al. (2014) identified a secondary phytoplankton bloom in the fall. This late season bloom coincided with delayed freeze-up, which allows more light penetration. At that critical time of year the open water also allows increased wind stress, which can cause the necessary nutrient upwelling for bloom formation.

Changes to sea-ice algal dynamics may have positive and negative effects on the species which feed upon them. Arrigo et al. (2008) suggested that in the Arctic the loss of ice during spring could potentially alter marine ecosystem structure and the degree of pelagic-benthic coupling. Nelson (2013) summarized the biodiversity and biogeography of the lower trophic taxa with sensitivities to climate change. The summary highlighted that changes in range and relative abundance of particular Arctic taxa have occurred over the last decade. These changes suggest lower trophic taxa are responding to one or multiple stressors.

2.2.3 Ocean Acidification

Ocean acidification in the Arctic has intensified due to low temperatures as well as an increase in the supply of naturally more acidic Pacific water and freshwater from river runoff and ice melt. Colder water increases CO₂ solubility and this causes increased

acidification, which is exacerbated by regional oceanographic features (high freshwater inputs and large continental shelf area relative to volume). These features limit the ocean's capacity to compensate for increased acidity. High productivity in the upper ocean, despite locally and temporarily mitigating acidification, results in increased CO₂ drawdown at the surface and CO₂ generation at depth during the subsequent remineralization of sinking organic matter. High productivity over the shelves in summer, upwelling of low pH waters, as well as major terrestrial organic carbon supplies from rivers and coastal erosion, ultimately result in further reduction of pH and calcium carbonate (CaCO₃) saturation state (AMAP 2013).

Aragonite and calcite are the two forms of CaCO₃ minerals commonly produced by marine organisms. The saturation state (Ω) of seawater with respect to CaCO₃ is a measure of its potential to corrode the CaCO₃ shells and skeletons of marine organisms and prevent the development of new shells and skeletons. CaCO₃ shells start to dissolve when the waters become undersaturated (when $\Omega < 1.0$) with respect to CaCO₃. However, decreased saturation states can have potential adverse effects on metabolism and also development of different life stages of marine fish and invertebrate species (AMAP, 2013; Falkenberg and Tubb, 2017). Averaged over the Beaufort Sea and Canada Basin, surface waters are still supersaturated (i.e., $\Omega > 1$), but upper halocline waters and deep waters now regularly show aragonite undersaturation with values around 0.8 in the subsurface and down to 0.7 for bottom waters (Miller et al., 2014). In 20 years from 1990 to 2010, low aragonite saturation (Ω_A) waters in the Western Arctic have expanded northwards by at least 5° latitude up to 85°N. These undersaturated waters have also deepened by 100 m from 1990 to 2010, to 250 m depth. Low aragonite saturation ($\Omega_A < 1$) water has increased from 5% to 31% in the upper 250 m north of 70°N (Qi et al., 2016). These results confirm the Western Arctic Ocean as the first open-ocean region with large-scale expansion of 'acidified' water directly observed in the upper-water column. Measurable downstream effects on seawater chemistry are propagated via the M'Clure Strait and Amundsen Gulf into waters of the Canadian Arctic Archipelago and beyond (AMAP, 2013). Model simulations suggest Arctic Ocean acidification will continue over the next century with accelerated reductions in CaCO₃ saturation state at least until the sea-ice cover reaches a new steady state with largely ice-free summers (Steiner et al. 2014).

Following the Representative Concentration Scenarios (RCPs, Moss et al. 2010), projections with RCP8.5 (no mitigation) forcing for the Canada Basin showed reductions in the bi-decadal mean surface pH from about 8.1 in 1986 – 2005 to 7.7 by 2066 – 2085, closely linked to reductions in the calcium carbonate saturation state Ω_{AC} from about 1.4 (2.0) to 0.7 (1.0) for aragonite (calcite). An emission scenario with mitigation (referred to as the RCP4.5) reduces the progress of acidification. A pH of 7.9 is reached about 25 years later than in an emission scenario without mitigation. However, the emergence of undersaturated surface waters, which is projected to occur within the next decade, differs little between the scenarios (Steiner et al. 2014).

2.2.4 Hypoxia

Hypoxia has not yet been highlighted as a major stressor in the Canadian Arctic and future oxygen trends in the Beaufort Sea are uncertain due to short observed oxygen time series (Carmack et al. 2010). Two large-scale oxygen trend analyses exhibit discrepancies

in the area. Ito et al. (2017) found increasing oxygen trends at depths of 100 m and 400 m for the time period from 1958 to 2015, whereas Schmidtke et al. (2017) found a rather large decreasing oxygen trend over the entire water column over the last 50 years with a latitudinal O₂ change of up to 6 μ mol per degree per decade north of 65°N.

2.2.5 Other Stressors

Additional stressors, including human habitation, overfishing, industrial and agricultural activities, increased shipping, noise, anthropogenic contaminants (including, more recently, micro- and nano-plastics), altered food-webs, and the introduction of invasive species (see review by Mølltoft, 2013), put additional pressure on the Arctic marine ecosystem. The ArcticNet Integrated Regional Impact Studies report on climate change and modernization (Allard and Lemay, 2012) points out that climate warming, combined with changes in the natural and socio-economic environment is creating cascading effects on the ecosystem and society with significant impacts on human health and quality of life, particularly via the impacts on food resources.

3. RESULTS

3.1 Aquatic Species Physiological Limits Database

Information on thermal tolerance indices (critical maximum temperature for loss of equilibrium, cardio-respiratory performance, optimum temperature, aerobic scope and acclimation potential) of key Canadian Pacific and Arctic commercial species has been reported in the scientific literature dating from the 1920s to present but has not been previously compiled. The ASPL database has 58 fields for data input (see Appendix 1). Temperature thresholds are considered primary drivers of an ectotherm-species distribution (Pörtner, 2001; Hochachka and Somero, 2002) and thus these thresholds and limits are a key focus of this dataset. However, also included in the database are single-stressor experiments that test dissolved salt content ($S_{\max}$ or $S_{\min}$), hypoxia tolerance ($O_{2\min}$) and various CO₂ exposures (pH), which can supersede temperature as the main driver of distribution and survival depending on life stage and habitat. These key parameters of life in aquatic habitats can be measured (and the data added to these same S, O₂, pH and the other 2 stressor fields in the database) in situ, with a CTD plus underwater drop camera (CTD/DC) for species identification, when collecting observational and oceanographic data.

Most of the database fields are self-explanatory, but some data fields were added to help with sub-topic analysis (see ASPL input form, Fig. 1). For instance, to help estimate acclimation potential the T_{opt} lat/long field provides a fixed location, which is required to estimate the acclimation conditions of a given population. The T_{opt} lat/long field would not be required when adding data from a laboratory study as the study would report acclimation temperature and duration prior to and during testing. There are 3 fields (Vulnerable life stage, Vulnerable season and Temperature limit) that require analysis of all the data available in the ASPL database to select the most ecologically relevant Temperature limit for the most vulnerable life stage. Most often the vulnerable season will be summer for upper limits and winter for cold tolerance limitation but the vulnerable season could vary when adding multi-stressors to the analysis.

Observational data can be very informative. For instance, it was observed that Atlantic cod (*Gadus morhua*) prefer water temperatures from 0 to 6°C. They will move into 8°C water to eat capelin but will not enter 9°C water regardless of capelin densities (Rose and Leggett, 1989). This observational study of Atlantic cod and their prey in the northeastern Gulf of St. Lawrence demonstrates that knowing a species location (their preferred seasonal habitats) and life history also allows us to define temperature optimum windows that could be the most ecologically relevant as the intensity of climate change stressors increases. In this case observation closely matched physiological data as adult Atlantic cod optimum temperature window (T_{opt} window) is 0 – 5°C and their $T_{max} = 8.5^\circ\text{C}$ (see ASPL Database – sp.'s ID#87). That these fish will not venture into 9°C water indicates a steep drop off in temperature tolerance past T_{max} . Ideally this will be verified in laboratory investigations. We hope there will be an increase in multi-stressor physiological studies that combine limits of salinity, oxygen and pH with temperature challenges to quantify more ecologically-relevant ectotherm species' behaviour responses, thresholds and limits to survival.

ID	14	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Boreogadus	soida	Polar cod (Europe)	Arctic cod (North Ameri)	7yrs	40cmTL	2017-11-15
Species code		Indigenous name	Imuktitut (I): Ogaq, Ogac, Ovac, Equauaq, Itok, Ögark, Uugaq Inuvialuktun (In): Uugavik			Reproduction	Data update info	
Economic species	Yes	Habitat notes	Cryopelagic, swarm during ice break up around coastal areas (1+yr olds) Larvae and juvenile live			1-2yr maturity males develop gonads in summer before female	Added fields: Indigenous name, FW/SW, ~~Temperature window~~	
Fresh and/or saltwater	☐ FW ☒ SW ☐ Both	Feeding notes	Omnivorous: especially copepods, amphipods, also can be cannibalistic (Drost, dir. obs.)			Spawning depth	Vulnerable life stage	
Species location	☒ Arctic ☒ SubArctic ☒ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance	Pan Arctic distribution -no definitive population DNA differences (Ref#16). Bering Sea(Ref#18)			Under ice - eggs neutrally buoyant	Larvae	
		Depth range	0- 1,390m (Ref#21)			Larvae 5-20m Up to 1yr 20-50m	Spawning date	
		Temperature optimum (Topt)	Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window	Winter under ice	Vulnerable season	
		Larvae (acclimation 3.5C) = 3.3C Ref#2	Acclimation 0.5C = 0.2C Acclimation 3.5C =	Eggs ~3.5C (Ref #2) Larvae ~7.6C (Ref#2) Adults Heart rate: #23	Reproduction: -1.4 to 3.5C(Ref#7, #23)	Hatch date	Temperature limit	
		Adults (acclimation 0.5C) = 1.0C				Arctic spring (March-July)	7.6C	
Conservation status notes		Topt (lat_long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	Justification provided ☒
		n/ap - Lab study	Adults@ RMR: Acclimation 0.5C = Acclimation 3.5C =	Sal_min	O2_min	pH_min	Other stressor2	Spp pic and rets compiled? ☒
Tcmax		Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies	Data quality check ☒
LOE-Adults (acclimation 0C) = 14.9C (acclimation 3.5C) =		-1.4C(Ref#23)	Adults: TAB Acclimation 0C = 3.6C Acclimation 3.5C = 4.7C Acclimation 6.5C = 4.3C	Sal_error	O2_error	pH_error	OA + temp using growth as index (Ref#4), OA + temp using Mitochondrial limits (Leo et al., 2017)	
Acclimation potential	Yes using Tcmax = 0.43 slope increase for every 1C increase in acclimation temp (from 1 to 6.5C) (Ref#3)							
References	#1. Drost, 2014; #2. Drost, 2015; #3. Drost, 2016; #4. Kunz, 2016; #5. Crawford et al., 2010; #6. Davis et al., 2016; #7. Kent et al., 2016; #8. Majewski et al., 2015; #9. Leo et al., 2017; #10. Harwood et al., 2015; #11. Andriyashev et al., 1980; #12. Craig et al., 1982; #13. Moulton and Tarbox, 1987; #14. Gradinger & Bluhm, 2004; #15. Majewski et al., 2013; #16. Nelson et al., 2013; #17. Fishbase.org; #18. Short et al., 2006; #19. Laurel et al., 2015; #20. Kent et al., 2016; #21. Coad & Reist, 2018; #22. Kuhn et al., 2018; #23. Hop & Tonn, 1998; #24. Villa et al., 2016;							
Data gap summary	No multiple stress studies have been conducted on eggs, larva but a few studies have included Temp + OA for adults using growth and mitochondrial leaking to quantify impact (Ref#4, 9). A few interesting species comparative studies (with Caplin primarily) but more need to be conducted with additional indicators of performance							
Notes	Fisheries: highly commercial (Ref#17). High load of perfluorooctane sulfonate (PFOS) found in Arctic cod (Ref#24) as well as microplastic (Ref#22). A suite of respiratory and heart rate sub-chronic and chronic transition temperatures (i.e. a Fry Polygon) are not entered in database (space limitation). See Ref#3 for details.							

Figure 1. Example input form for the ASPL database

This form can be sent to contributors and reintegrated into the ASPL database without data conflict. There is a single table with 58 data fields (see Appendix 2) that supports the input form, queries and reports. There is a second table in the ASPL database that contains contact details for contributors.

The ASPL database is also designed for Indigenous Knowledge (IK) inclusion and fosters co-production of knowledge regarding the assessment of species physiological thresholds and limits. This is a living database that requires continuous additions of observational, IK and experimental data. We hope existing and future Indigenous coastal-watch programs, especially in remote regions where so many species of interest exist, will help expand this ASPL database and provide the necessary ground-truth data for model applications.

3.2 Thresholds for Selected Species

To date a list of 90 Arctic species has been compiled in the ASPL database (Appendix 6.1a.), however information on physiological tolerances was only available for 17 of those species with only 6 species having information on pH responses. Optimum temperatures generally cover very small ranges of 1 – 4°C and can vary significantly among life stages (adults, juveniles, larvae, and eggs (i.e. hatching ability)). For example, optimum temperatures for capelin are 2.5 – 10.8°C for spawning, 1 – 19°C for egg hatching, 4.5 – 9°C for larvae, 5 – 7°C for juveniles and -1 – 6°C for adults. Table 1 gives a summary of optimum temperatures, critical temperatures and pejus temperatures for these 17 species. Information on thermal acclimation is available for Arctic cod and Arctic char and indicates that these fish are able to acclimate to a certain extent. It appears that acclimation to higher temperatures only leads to slight changes in upper critical temperature. For instance, Arctic char that are acclimated to 5°C water leads to critical upper temperatures of 23.3, 25.1 and 25.7°C for just hatched (alevins), early-feeding (fry) and juvenile (parr) fish respectively. Acclimation to 20°C for these life stages leads to critical upper temperatures of 26.2, 26.1 and 26.6°C respectively. For Arctic cod adults, critical upper temperature changes from 14.9°C to 17.1°C, depending on their acclimation temperature. The critical upper temperature changes are a good way to quantify acclimation potential yet these temperatures are not presently experienced by Arctic cod in the wild. The much lower maximum temperature (T_{max}) for spawning is 3.5°C (Kent et al., 2016), which occurs in the winter under sea-ice. However, due to the season and location of Arctic cod spawning, the spawning temperature maximum is also not considered the limiting factor. Juvenile and young adult life stages are found (often in swarms) in coastal waters during ice break up and during the summer months they are probably at their most vulnerable with T_{opt} windows between 0 and 6°C and a T_{max} of ~10°C (depending on acclimation). Surface coastal water in Cambridge Bay can now reach 10°C in summer months (Neptune; Drost et al., 2016). It is not known if Arctic cod need access to surface waters, but exceeding optimum or preferred water temperatures can influence distribution (Steiner et al., 2015). Exceeding optimum temperatures can impact overall performance and potentially lead to deleterious competitive interactions with Subarctic species, such as capelin that are increasing in abundance since the 1980's in Darnley Bay within the ISR (Lawrence Rubin - Inuvialuit Game Council member, pers. comm.).

3.3 Species physiological limits and Acclimation Potential

The impact of global warming on the physiology of ectotherm marine species (e.g. fish, copepods, bivalves) is of particular concern due to an ectotherms total reliance on habitat temperature to maintain body heat. Temperature drives metabolism and hence basic performance including: development, growth, reproduction and survival (Pörtner, 2001;

Hochachka and Somero, 2002; Brown et al., 2004). Species may respond differently at different life stages. If the environmental changes are significant enough at the location, depth and season where the species resides it could expose them to conditions outside their optimal performance windows. This could make them less competitive or make the environment unsuitable for living.

Sub-chronic limits to performance are potentially important as drivers of marine species distribution (Drost et al., 2016). Traditionally, critical temperature (T_{cmax}) limits were the focus of many early physiological studies and are still used in species distribution models. Much more research on sub-chronic physiological limits is needed, such as when aerobic performance first starts to decline or when heart rate continues to increase, but not as quickly despite steadily increasing water temperatures (T_{AB}) (Fry, 1947, 1971; Brett, 1971; Iwaya-Inoue et al., 1989; Frederich & Pörtner, 2000; Pörtner & Farrell, 2008; Casselman, 2012; Drost et al., 2014).

Fish, even true stenothermal Antarctic fish species, are able to acclimate to warmer temperatures (Pörtner et al., 2000; Lanning et al., 2005; Seebacher et al., 2005; Franklin et al., 2007; Robinson and Davidson, 2008; Peck et al., 2014; Farrell et al., 2017). Acclimation is the ability of a species to adjust to a change in environmental conditions and maintain optimum performance. Arctic cod have the ability to acclimate to different temperatures depending on the duration of exposure. Acclimation for one month to warmer water temperatures increases adult Arctic cod temperature maximum (T_{max}) from 10.8°C for 0.5°C acclimation to 12.3°C for 3.5°C acclimation (Drost et al., 2016). The T_{max} is at the peak, before heart rate levels out or declines despite steadily increasing water temperatures. So this fish species may be capable of adjusting their tolerances over time to acclimate to environmental changes. Respiratory performance can also be used to quantify acclimation potential. For instance, Arctic cod are able to increase their aerobic scope (capacity to supply O_2 for activity) to a certain extent (by 4.5°C when acclimated from 1.0 to 6.5°C). Loss of equilibrium ($T_{\text{cmax(LOE)}}$) can also be used to estimate acclimation potential. Arctic cod increased their tolerance to lethal temperatures by 2.3°C over that same temperature range. The potential to acclimate (e.g. thermal plasticity in fish) requires further study and this potential should be included in ecosystem models that forecast climate change impacts on food-webs (Farrell and Franklin, 2016).

Clearly fish have some capacity for thermal acclimation yet climate change multi-stressors may impact the ability of marine fish to acclimate. Recent experiments on Atlantic cod cardiac mitochondria performance indicate that acclimation potential might be constrained by high temperature and pCO_2 (Leo et al., 2017). Studies that quantify the cumulative impacts of multi-stressors (such as temperature, ocean acidification, noise and hypoxia) on various physiological, molecular, reproduction, growth, survival, behaviour and body condition and behaviour indices are urgently required.

Species common name:	Temperature limits (°C)				pH limits	Vulnerable life stage to increasing	Key sources
	Critical lower	Lower pejus / T_{min}	Upper pejus / T_{max}	Critical upper	Critical/Pejus/Optimum	water temperature	
Sablefish	Juveniles (Juvs) = 2C		Adults = 16C Juvs = 15C	Spawning adults & eggs = 6C		TBD	Lee et al., 2017; Mason et al., 1983
Pacific cod	Egg < 0C	Eggs/larvae = 2C	Eggs/larvae: 8C	Adults = 20C Eggs/larvae = 14C		TBD	Forrester and Alderdice, 1966
Pacific herring		Adults = 4.7C		Spawning = 10C Larvae = 13.3C (at 25ppm)		TBD	Alderice and Velsen, 1971
Spot prawn	Adults = 3C	Adults = 5C	Eggs = 13-15C	Adults = 21C Larvae = 15.2C		TBD	King, 1997
Geoduck	Spawning = 7C	Egg = 6C Spawning = 8.5C	Adults = 18C	Adults = 22C		TBD	Goodwin and Pease 1989; anecdotal information from Arney et al., 2015
Pacific Ocean Perch		Adults & Juvs = 4C		Adults & Juvs = 9.5C		TBD	Scott, 1995; Laman et al., 2015; Snytko, 1971
Arrowtooth Flounder	Egg ≤ 1C	Spawning = 4.3C	Spawning = 5.4C	Egg = 6.2C		TBD	Blood et al., 2007
Spiny Dogfish		Adults = 7C	Adults = 15C			TBD	Ebert et al., 2010; Andrews and Harvey, 2013
Pacific Hake	Eggs hatching = 11C Adults = 3.5C	Adults = 9C	Adults = 15C	Egg hatching > 14C Adult distribution > 17.5C		TBD	Moser et al., 1997;
Arctic cod	-1.4C	Adults = 0.2C	Spawning = 3.5C Adult heart rate (T_{max}) = 10.8C	Adult Loss of equilibrium ($T_{cmax(LOE)}$) = 14.9C	No difference in proton leak and ATP production efficiency between groups acclimated at 400 μ atm vs. 1170 μ atm of CO ₂	Larvae in summer at surface = 7.6C 1+yr & Adults in summer at surface = 10.8C	Drost et al., 2014; Kent et al., 2016; Laurel et al., 2015; Kunz et al., 2016; Leo et al., 2017

Species common name:	Temperature limits (°C)				pH limits	Vulnerable life stage to increasing	Key sources
	Critical lower	Lower pejus / T_{min}	Upper pejus / T_{max}	Critical upper	Critical/Pejus/Optimum	water temperature	
Arctic char	0C	Eggs < 3C	Adults = 16C Adults Growth freshwater = 15.1C T_{max} (heart rate) = 23C	larvae feeding = 22C. Alevins, fry and parr (acclimation 5C) = 23.3, 25.1 and 25.7C	Pejus = CO ₂ <10 mg/L optimum 10-20 mg/L	TBD	Sutterlin and Stevens, 1992; Thyrel et al., 1999; Quinn et al., 2011; Musa, 2013; Penney et al., 2014; Hansen et al., 2017; Jeuthe et al., 2016
Capelin	-1.5C	0C	Juveniles= 10C Adults= 14C			TBD	Fortier and Leggett, 1985; Rose and Leggett, 1989; Rose, 2005
Pacific halibut		Adults = 3	Adults = 8C			Juveniles in May/June at surface = 8C	IPHC, 1998
<i>Calanus glacialis</i> (copepod)			10C or = 5C with 3000 μ atm added stress		Hatching delay: 6.9 pH Copepodites stage IV: 7.87 pH	TBD	Weydmann et al., 2012; Hildebrandt et al., 2014; Thor et al., 2017
<i>Limacina helicina</i> (pteropod)	Adults = -1.9C	Adults = -0.4	Adults = 7C		Adult: 28% decrease in calcification at 760 μ atm. $\Omega \sim 0.8$ = severe damage	TBD	Comau et al., 2009; Bednaršek et al., 2012
Surf clam	Adults = 1.9C			Adults = 9.7C			Encyclopedia of life, FAO- <i>Spisula polynyma</i> , 2015
Atlantic cod	Adults = -1.2C Larvae = 4C		Adults = 10C	Adults = 20C Larvae = 12-15C	Significant tissue damage in liver, pancreas, kidney, eye, and gut of larvae under elevated pCO ₂	Planktonic larval stage in spring/summer at surface = 12C	Shackell et al., 2013; Rose and Leggett, 2011; Frommel et al., 2012; Laurence, 1978; Iversen & Danielssen, 1984

Table 1. Summary table of selected species temperature and pH threshold information

Ecologically relevant threshold data for some key Arctic and Subarctic species were exported from the ASPL database for this table. Adult life stage is assumed when not specified. The limits reported in the database and emphasized here include sub-chronic thresholds that are termed “pejus” limits. These are tipping points when performance begins to decline. A quality control (QC) check button is included in the database. Optimum temperature (T_{opt}) data are included in the database, but were not included to limit table size and increase clarity.

4: DISCUSSION

4.1 Focus Species: Arctic Cod (*Boreogadus saida*)

Presenting modellers and resource managers with a single, critical temperature limit for a given species is difficult if the ecological footprint of a species is not included in the analysis of temperature tolerance. Both spatial and temporal data for each species must be included (see ASPL database columns for depth, reproduction and seasonal migration details). The importance of life history and habitat to identify ecologically relevant physiological limits can be shown using Arctic cod as an example.

Within the literature, common names used for *Boreogadus saida* (Fig. 2) include both Arctic cod and Polar cod. In this report we will use Arctic cod exclusively. Figure 3 diagrams the primary role of Arctic cod in the transfer of energy from zooplankton to Arctic mega fauna. Due to the ecological key role of Arctic cod, changes at the base of the sea-ice associated food-web are likely to affect the higher trophic levels of high-Arctic ecosystems (Kohlbach et al., 2017). Predation upon them efficiently moves a large proportion of the energy and nutrients from Arctic algae and invertebrates to higher trophic levels (Bain and Sekerak, 1978; Welch et al., 1993; Crawford and Jorgenson, 1996; Christiansen et al., 2012; Hope and Gjøsæter, 2013).



Figure 2: Arctic cod from Cambridge Bay, Nunavut

a) Arctic Cod swarm, near Cambridge Bay in 2012 and b) Arctic cod collection, with help from community members, for scientific research (Photos H. Drost)

Arctic cod survive in ice-covered, sub-zero waters due to the presence of anti-freeze glycoproteins, specialized kidney function (Osuga and Feeney, 1978; Christiansen et al., 1996) and the ability to digest food at -1.4°C (Hop and Tonn, 1998). Arctic cod is considered an ecological key species, because it reaches high stock biomasses and constitutes an important carbon source for seabirds and marine mammals in high Arctic ecosystems (Bradstreet et al., 1986; Coad and Reist, 2004; Kohlbach et al., 2017). A recent assessment of fish assemblages in the Beaufort Shelf and Slope (Beaufort Sea Marine Fishes Project) indicated that Arctic cod typifies each of the four species assemblages (near-shore shelf, off-shore shelf, upper-slope, lower-slope) to varying degrees. The high abundance of Arctic cod at upper-slope stations were a major structuring feature of the fish community, strongly discriminating among the upper-slope assemblage and the outer-shelf and lower-slope assemblages (Majewski et al. 2013, 2015, 2017). Other studies in the Beaufort Sea have reported Arctic cod as the most abundant

demersal species across a range of habitats (Rand and Logerwell, 2010; Majewski et al., 2013; Walkusz et al., 2013).

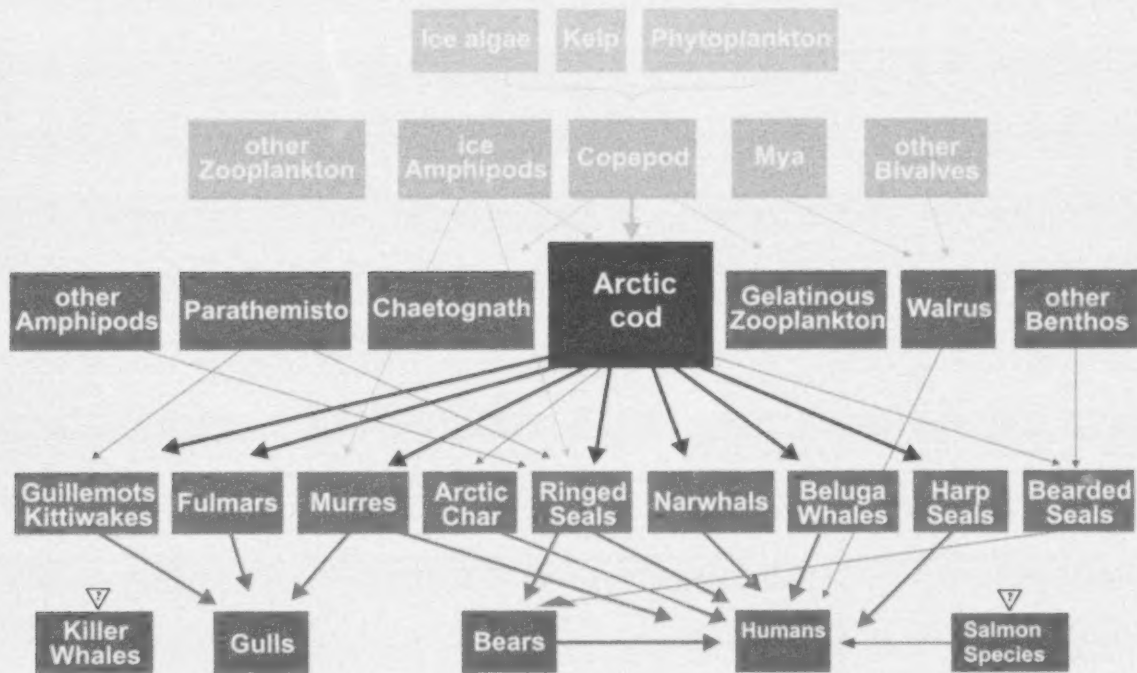


Figure 3: Canadian Arctic marine food-web

The food-web is centered on the key fish species Arctic cod (*Boreogadus saida*). Boxes without arrows indicate limited contribution and boxes with question marks above indicate unknown contribution to the food web. Diagram adapted from Welch et al. (1992).

Young Arctic cod (1 – 2 years) are often associated with the underside of sea-ice feeding on ice-associated (sympagic) amphipods, indicating a high importance of sympagic fauna in young Arctic cod diets (Kohlbach et al., 2016, 2017). Fatty acid profiles of Arctic cod indicate that diatoms are the primary carbon source, indirectly obtained via amphipods and copepods (Kohlbach et al., 2017). This highlights a strong dependency of Arctic cod on ice-algae produced carbon but also suggests a particular vulnerability to changes in the distribution and structure of sea-ice habitats.

There are empirical observations of a northward retreat of Arctic cod from their southernmost distributions, e.g., waters off Disko Bay, Greenland, Iceland-East Greenland waters, the Barents Sea and in the ISR (Hansen et al., 2012; Farrell et al., 2013; Astthorsson, 2015; Harwood et al., 2015). This observed northward shift in Arctic cod distribution would not have been predicted to have started this quickly based solely on their recently discovered cardio-respiratory thermal limits (Drost et al., 2014). Unless compounded multi-stressors (e.g. CO₂, reduced O₂) further decrease Arctic cod thermal tolerance, the results from these single variable thermal limits studies suggest that other factors may be influencing the present day distribution of Arctic cod. For instance, there could be

negative interactions with capelin (potential competitor) and two salmon species (potential predators) that are migrating in greater numbers now into the Western Arctic (Dunmall et al., 2013, Suprenand & Hoover, 2017). There is also evidence of a northward spread of Pacific zooplankton into the Beaufort Sea (Nelson et al., 2009, 2013) which might affect foraging by upper trophic species.

4.2 Food-web impacts of Changes in Forage Species

Food-web model results (Ecopath with Ecosim-EwE) suggest a reduction in Arctic cod biomass would likely have a negative impact on the Beaufort Sea marine ecosystem and would threaten walrus and ringed seal populations (Suprenand and Hoover, 2017). This suggests a cascading impact could occur throughout the entire Arctic marine ecosystem. Analyzing body condition since the late 1980s in five marine vertebrate species, Harwood et al. (2015) identified ringed seal, beluga and black guillemot chicks (all consumers with a dietary preference for Arctic cod), to experience declines in condition, growth and/or production. Over the same time period, they found increasing body condition in sub-adult bowhead whales and Arctic char, in both cases influenced by sea-ice changes. Reduction of summer sea-ice extent, including increased duration of open water, changes in upwelling potential (wind stress) and possibly higher primary production in the marine ecosystem favour herbivorous zooplankton that are targeted by bowhead whales (Lowry et al., 1978; Walkusz et al., 2012; Nelson et al., 2013). The diet of Arctic char includes a substantial number of Arctic cod in some years and is dominated by zooplankton in other years (Harwood et al., 2015; Fig. 4). Harwood et al. (2015) stated that the proximate causes of the observed changes in body condition remain unknown, but may reflect an upward trend in secondary productivity (zooplankton) and a concurrent downward trend in the availability of forage fishes, such as the preferred Arctic cod. Among other factors, the body condition of marine vertebrates is directly linked to the total annual availability and quality of their prey, with nutritional stress ultimately linked to health of individuals and populations (Moore and Gulland, 2014). The whale, seal and fish species analyzed by Harwood et al. (2015) are all important subsistence species in the Western Canadian Arctic. Hence, a demise of Arctic cod populations could impact subsistence and commercial fisheries (Thorsteinson and Love, 2016).

While changes in ice conditions currently seem to favour zooplankton production, which could lead to an overall positive impact on subsistence fisheries, increasing Arctic Ocean acidification and reductions in the CaCO_3 saturation state might pose negative effects on some Arctic zooplankton species. A summary of responses of primary producers to ocean acidification is given in Falkenberg et al. (2017) and AMAP (2018) and indicates variable responses from phytoplankton with overall fair resilience (Hoppe et al., 2017a,b) and negative effects mostly for calcifying species (Yoshimura et al. 2013; Thøiesen et al. 2015). Arctic pteropods are another species suggested to be negatively impacted by temperature and ocean acidification (Comeau et al., 2010, 2012; Lischka and Riebesell, 2012). For the Arctic copepod *Calanus glacialis* ocean acidification effects seem to vary with developmental stage. The developmental rate of nauplius larvae and the last copepodite stage appears largely unaffected whereas the earlier copepodite stages show increases in metabolic rates and decreased scope for growth due to feeding at high $p\text{CO}_2$ levels (Thor et al. 2017). Such changes to earlier copepodite stages could have serious implications for the *C. glacialis* population, including prolonged stage development time, reductions in the individual body size of the developing copepodites and ultimately also

the adults. Changes in *C. glacialis* populations could have serious impacts up the food-web.

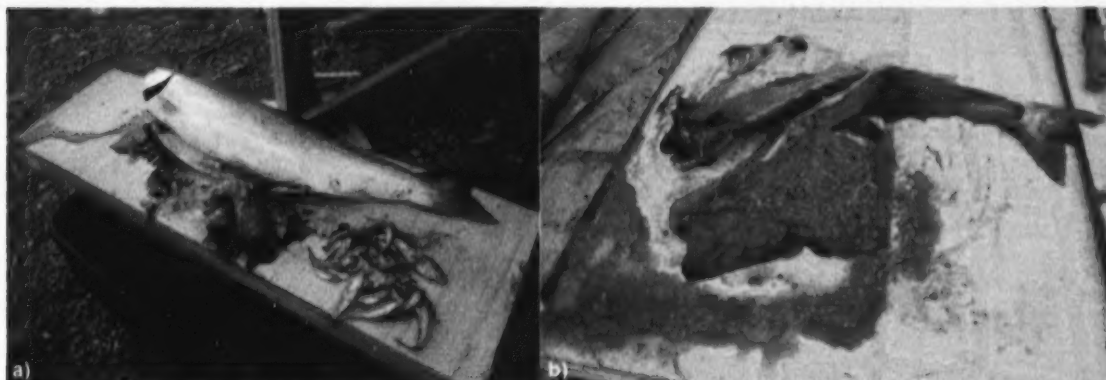


Figure 4: Arctic char stomach contents in 2011 and 2012

a) Arctic char stomach contents containing about 40 Arctic cod (Cambridge Bay, 2012) and b) Arctic char stomach contents dominated by zooplankton (Cambridge Bay, 2011) (Photos: H. Drost).

Despite the potential threat to an entire marine ecosystem and the Inuit peoples' subsistence livelihood, only a few laboratory-based thermal tolerance studies of Arctic cod exist and even fewer quantify the impact of multi-stressors (Kunz et al., 2016; Leo et al., 2017). To date, no study has quantified multi-stressor impact on Arctic cod cardio-respiratory performance.

This case study highlights the need to capture life stage and seasonal species-specific information in an eco-physiological database of temperature thresholds for aquatic species to adequately predict change in marine species distribution and abundance due to climate change driven changes in their environment.

4.3 Application in Higher Trophic Level Model Projections

Dynamic bioclimatic envelope models (DBEM) assess potential shifts in species distribution by tracking changes in the environmental variables within the current preferred distribution range of a species. Supported by observations, DBEMS already predict Arctic food-web shifts (W. Cheung – University of BC, pers. comm.). With respect to uncertainties within the DBEM, current DBEMs project changes in the distribution and abundance of species on fairly coarse resolution grids which tend to inadequately capture coastal processes. Further, the DBEM runs simulate only one species at a time and thus assume biological interactions and ecosystem effects are constant. Biological components could restrict or facilitate changes in distribution and abundance. In addition, most DBEMs only take into account surface and bottom temperatures. However, fish species inhabit a large range of depth intervals and might choose depth levels which are less prone to change and where they are less vulnerable.

Ocean acidification effects on species are highly variable, however current DBEMs assume linear relationships for the effects of ocean acidification on life history parameters, yet other mechanisms may be possible (T. Tai – University of BC, pers.

comm.). For example, a threshold relationship would initially show minimal responses to ocean acidification, but have exponentially greater impacts after a minimum threshold was crossed. Potential acclimation/adaptation to ocean acidification or other stressors is also not included in these models yet.

For food-web models like Ecopath with Ecosim (EwE), uncertainties are based on assumptions made to calculate or estimate parameters in the initial model, and changes over time. Considering the initial Ecopath model, input parameters are ranked based on the level of assumptions made when setting initial parameters. Generally, most information is available for marine mammals including key parameters (biomass, production, consumption), as well as diets and changes over time, with information often based on local studies that examine the populations in the modeled areas. For these groups confidence in population levels and role in the ecosystem is highest. Much of the information about links in the food-web come from research on higher trophic levels (stable isotopes and fatty acid analysis), giving insight into the structure and function of the lower trophic levels.

Fish groups are some of the biggest uncertainty in terms of Arctic ecosystem research, as only recently large-scale assessments on numbers of local species have been conducted under the BREA-Marine Fishes program (2012 – 2015). Before this study, only limited coastal programs were the main source of biological parameters, numbers and relative abundance of fish for the region and biological parameters were estimated based on the same or similar species in other regions. Zooplankton and production studies on abundance, distribution and food-web role have occurred more recently, providing more relevant information on these groups. We still only have an incomplete understanding of diets from the food-web perspective, so switching from specialists to generalists adds uncertainty to individual species and ecosystem impacts. While fish groups are the least certain in terms of the EwE model, this does not mean that there is no knowledge of this group, but rather we have to rely on information from other systems, species-specific studies and expert information (C. Hoover, pers. comm.).

5. CONCLUSION

A literature review was conducted to generate a database with physiological tolerance information for fish and invertebrate species found in Canadian Arctic/Subarctic waters. Attention was paid to document information by life stage and population or study area. The information gathered from relevant literature was assembled in a MS ACCESS database. At this point a list of 90 Arctic species has been compiled, however information on physiological tolerances was only available for 17 of those species, temperature acclimation information was available for 2 species and 6 species have information on pH responses.

Synthesizing the available eco-physiological data highlights the large gaps in our understanding of aquatic species responses to single- or multiple-variable changes in environmental conditions. To adequately understand impacts of climate change and other stressors on Arctic marine species it is paramount to understand the physiological response of individual species and the encompassing ecosystem to multiple stressors. Only detailed understanding will allow us to potentially parameterize those responses in models and project climate change impacts on Arctic marine ecosystems.

A thorough understanding of the ecophysiology of Arctic marine species requires observational and Indigenous Knowledge data to track migration patterns and species interactions as well as physiological testing in controlled laboratory settings to quantify the impact of climate change and other stressors (e.g. ocean acidification) on key marine species. Laboratory studies can quantify physiological responses to single and multiple stressors by assessing the sub-chronic limits under controlled conditions for different life stages, and thus lead to an understanding of where and when a species might be most vulnerable.

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8. APPENDICES

Appendix 1: List of species (to date)

Genus	Species	Common name (1)
<i>Anoplopoma</i>	<i>fimbria</i>	Sablefish
<i>Gadus</i>	<i>macrocephalus</i>	Pacific cod
<i>Clupea</i>	<i>pallasii</i>	Pacific herring
<i>Pandalus</i>	<i>platyceros</i>	Spot prawn
<i>Panope</i>	<i>generosa</i>	Pacific geoduck
<i>Sebastes</i>	<i>alutus</i>	Pacific Ocean perch (POP)
<i>Atheresthes</i>	<i>stomias</i>	Arrowtooth Flounder
<i>Microstomus</i>	<i>pacificus</i>	D over/Pacific sole
<i>Squalus</i>	<i>suckleyi</i>	Pacific spiny dogfish
<i>Sebastes</i>	<i>entomelas</i>	Widow Rockfish
<i>Sebastes</i>	<i>paucispinis</i>	Boccaccio Rockfish
<i>Gadus</i>	<i>chalcogrammus</i>	Walleye pollock
<i>Merluccius</i>	<i>productus</i>	Pacific hake
<i>Boreogadus</i>	<i>saida</i>	Polar cod (Europe)
<i>Salvelinus</i>	<i>alpinus</i>	Arctic char
<i>Pandalus</i>	<i>borealis</i>	Arctic shrimp, Northern shrimp
<i>Reinhardtius</i>	<i>hippoglossoides</i>	Greenland Halibut
<i>Calanus</i>	<i>hyperboreus</i>	copepod
<i>Mytilus</i>	<i>edulis</i>	Blue mussel
<i>Chionoecetes</i>	<i>opilio</i>	Snow crab
<i>Strongylocentrotus</i>	<i>droebachiensis</i>	Green sea urchin
<i>Cucumaria</i>	<i>frondosa</i>	Brown sea cucumber
<i>Psolus</i>		Sea cucumber
<i>Myriotrochus</i>		Sea cucumber
<i>Lampetra</i>	<i>camtschaticum</i>	Arctic lamprey
<i>Amblyraja</i>	<i>hyperborea</i>	Darkbelly Skate
<i>Raja</i>	<i>stellulata</i>	Starry skate
<i>Oncorhynchus</i>	<i>gorbuscha</i>	Pink salmon
<i>Oncorhynchus</i>	<i>keta</i>	Chum salmon

<i>Coregonus</i>	<i>autumnalis</i>	<i>Arctic cisco</i>
<i>Thymulus</i>	<i>arcticus</i>	<i>Arctic greyling</i>
<i>Salvelinus</i>	<i>malma</i>	<i>Dolly varden</i>
<i>Mallotus</i>	<i>villosus</i>	<i>Capelin</i>
<i>Ammodytes</i>	<i>hexapterus</i>	<i>Sand lance</i>
<i>Hippoglossus</i>	<i>stenolepis</i>	<i>Pacific halibut</i>
<i>Gammarus</i>		<i>Gammariid amphipods</i>
<i>Onisimus</i>		<i>Gammariid amphipods</i>
<i>Coregonus</i>	<i>chupeaformis</i>	<i>Lake whitefish</i>
<i>Calanus</i>	<i>glacialis</i>	<i>Copepod</i>
<i>Osmerus</i>	<i>mordax</i>	<i>Rainbow smelt</i>
<i>Themisto</i>	<i>libellula</i>	
<i>Ulcina</i>	<i>olrikii</i>	<i>Arctic alligatorfish</i>
<i>Leptagonus</i>	<i>decagonus</i>	<i>Atlantic poacher</i>
<i>Gymnocanthus</i>	<i>tricuspis</i>	<i>Arctic staghorn</i>
<i>Triglops</i>	<i>pingelii</i>	<i>Ribbed sculpin</i>
<i>Lycodes</i>	<i>polaris</i>	<i>Canadian eelpout</i>
<i>Lycodes</i>	<i>adolphi</i>	<i>Adolf's eelpout</i>
<i>Lycodes</i>	<i>seminudus</i>	<i>Longear eelpout</i>
<i>Metridia</i>	<i>longa</i>	
<i>Limacina</i>	<i>helicina</i>	<i>Pteropod</i>
<i>Eukrohnia</i>	<i>hamata</i>	<i>Chaetognaths</i>
<i>Apherusa</i>	<i>glacialis</i>	<i>Gammariid amphipod</i>
<i>Spisula</i>	<i>polynyma</i>	<i>Surf clam</i>
<i>Paralithodes</i>	<i>camtschaticus</i>	<i>King crab</i>
<i>Chionarcetes</i>	<i>tanneri</i>	<i>Tanner crab</i>
<i>Limanda</i>	<i>aspera</i>	<i>Yellowfin sole</i>
<i>Rhodichthys</i>	<i>regina</i>	<i>Snail fish</i>
<i>Paralichthodes</i>	<i>glacialis</i>	<i>Right eye flounder</i>
<i>Hippoglossoides</i>	<i>robustus</i>	<i>Bering flounder</i>
<i>Hippoglossoides</i>	<i>platessoides</i>	<i>Canadian plaice</i>
<i>Liopsetta</i>	<i>proboscidea</i>	<i>Longhead dab</i>
<i>Liopsetta</i>	<i>putnami</i>	<i>Smooth flounder</i>

<i>Platichthys</i>	<i>stellatus</i>	<i>Starry flounder</i>
<i>Myoxocephalus</i>	<i>scorpioides</i>	<i>Arctic sculpin</i>
<i>Coregonus</i>	<i>artedi</i>	<i>Cisco</i>
<i>Lycodes</i>	<i>brevipes</i>	<i>Shortfin eelpout</i>
<i>Amblyraja</i>	<i>radiata</i>	<i>Thorny skate</i>
<i>Somniosus</i>	<i>microcephalus</i>	<i>Greenland shark</i>
<i>Sebastes</i>	<i>mentella</i>	<i>Redfish, ocean perch</i>
<i>Sebaste</i>	<i>orange</i>	<i>Golden redfish</i>
<i>Sebaste</i>	<i>atlantique</i>	<i>Deepwater redfish</i>
<i>Myoxocephalus</i>	<i>scorpius</i>	<i>Shorthorn sculpin</i>
<i>Cyclopters</i>	<i>lumpus</i>	<i>Lumpfish</i>
<i>Lycodes</i>	<i>esmarkii</i>	<i>Greater eelpout</i>
<i>Lycodes</i>	<i>reticulatus</i>	<i>Arctic eelpout</i>
<i>Anarhichas</i>	<i>denticulatus</i>	<i>Northern wolffish</i>
<i>Notacanthus</i>	<i>chemnitzii</i>	<i>Snubnosed Spiny Eel</i>
<i>Prosopim</i>	<i>cylindraceum</i>	<i>Round whitefish</i>
<i>Nezumia</i>	<i>bairdii</i>	<i>Marlin-spike</i>
<i>Eleginus</i>	<i>gracilis</i>	<i>Saffron cod</i>
<i>Stenodus</i>	<i>leucichthys</i>	<i>Inconnu</i>
<i>Coregonus</i>	<i>nasus</i>	<i>Broad whitefish</i>
<i>Oncorhynchus</i>	<i>kisutch</i>	<i>Coho salmon</i>
<i>Gadus</i>	<i>ogac</i>	<i>Greenland cod</i>
<i>Gadus</i>	<i>morhua</i>	<i>Atlantic cod</i>
<i>Lycodes</i>	<i>jugoricus</i>	<i>Shulupaoluk</i>
<i>Macoma</i>	<i>calcareo</i>	<i>Bivalve</i>
<i>Astarte</i>	<i>montagui</i>	<i>Bivalve</i>
<i>Astarte</i>	<i>borealis</i>	<i>Bivalve</i>
<i>Chaetoceros</i>	<i>socialis</i>	<i>Diatom</i>

Appendix 2: List of data fields

Field	Data
1	<i>Species code</i>
2	<i>Species ID</i>
3	<i>Economic species</i>
4	<i>Fresh or saltwater</i>
5	<i>Genus</i>
6	<i>Species</i>
7	<i>Common name (1)</i>
8	<i>Common name (2)</i>
9	<i>Indigenous name</i>
10	<i>Conservation status notes</i>
11	<i>Life span estimate</i>
12	<i>Max length</i>
13	<i>Species location</i>
14	<i>Distribution and Abundance</i>
15	<i>Depth range</i>
16	<i>Depth preferred</i>
17	<i>Reproduction</i>
18	<i>Spawning depth</i>
19	<i>Spawning date</i>
20	<i>Hatch date</i>
21	<i>Habitat notes</i>
22	<i>Feeding notes</i>
23	<i>Temperature optimum (Topt)</i>
24	<i>Tmin (or Tlpejus)</i>
25	<i>Tmax (or Tupejus)</i>
26	<i>Topt window</i>
27	<i>Topt (lat & long)</i>
28	<i>Respiration data</i>
29	<i>Heart rate data</i>
30	<i>Tcmax</i>
31	<i>Tcmin</i>
32	<i>Sal_max</i>
33	<i>Sal_min</i>
34	<i>Sal_opt</i>
35	<i>Sal_error</i>
36	<i>O2_max</i>
37	<i>O2_min</i>
38	<i>O2_opt</i>
39	<i>O2_error</i>
40	<i>pH_max</i>
41	<i>pH_min</i>
42	<i>pH_opt</i>

Field	Data
43	<i>pH_error</i>
44	<i>Other stressor1</i>
45	<i>Other stressor2</i>
46	<i>Multiple stress studies</i>
47	<i>Acclimation potential</i>
48	<i>References</i>
49	<i>Data gap summary</i>
50	<i>Data update date</i>
51	<i>Data update information</i>
52	<i>Vulnerable life stage</i>
53	<i>Vulnerable season</i>
54	<i>Temperature limit</i>
55	<i>Data quality check?</i>
56	<i>Spp pic and refs compiled?</i>
57	<i>Justification provided?</i>
58	<i>Notes</i>

Note: Not all fields are included in the input form (Fig. 1)

Appendix 3: Data sheets for species listed in Table 1.

ID	1	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Anaplopoma	fimbria	Sablefish	Black cod	100 yrs. (Ref#1)	Female 110cm (43 in.)	2017-11-17
Species code		Indigenous name					Reproduction	Data update info
Economic species	Yes	Habitat notes					Female mature at 69cm (6.5yrs), males 80-90cm (6.5-7yrs)	Acclimation potential
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Feeding notes					Spawning depth	Vulnerable life stage
Species location	☐ Arctic ☒ SubArctic ☒ Bering Sea ☒ NPacific ☐ INWPac ☐ NEPac	Distribution and Abundance					Spawning date	Vulnerable season
Conservation status notes		Temperature optimum (Topt)					Spawning adults & developing eggs < 5C (Ref#2)	Temperature limit
Topt (lat-long)		Respiration data					Sal_max	Other stressor1
Tmin		1kg fish = 100mg O2/kg/h (Ref#13)NB: RMR data at 10C (not					Sal_min	Other stressor2
Tcmax		Heart rate data					Sal_opt	Multiple stress studies
Tcmin		25-35 ppm (R					Sal_error	Shotwell et al. developed conceptual model of 3 mechanisms - Ocean Domain Dynamic Synergy (ODDS), which influences sablefish survival through the pelagic early life history stage.
Acclimation potential		All fish reared between 8 and 10°C with the exception of 1 group reared in surface-floating pens experiencing summer high temperatures of 18°C (Ref#14)					Data quality check	
References								
#1. King et al., 2001; #2. Mason et al., 1983; #3. King et al., 2000; #4. McFarlane & Beamish, 1992; #5. Boehlert & Yoklavich, 1985; #6. Alderdice et al. 1988; #7. Coffin & Mueter, 2016; #8. Echave, 2012; #9. Kendall & Matarese, 1987; #10. http://marine.troutlodge.com , 2017; #11. Lee et al., 2017; #12. Coutre, 2015; #13. Shotwell et al., 2014; #14. Sullivan & Smith, 1982; #15. Kennedy, 1969;								
Data gap summary								
No metabolic limits physiology found to date. A spatial sablefish model has been developed at University of Alaska-Fairbanks but the management strategy evaluation is in early stages of development. A year-class index was developed as an early indication of recruitment for the British Columbia stocks (Ref#3)								
Notes								
Upwelling-favorable winds and freshwater discharge may affect recruitment (Ref#7). The year class success exhibit decadal-scale patterns. The periods with above average year classes were generally characterized by intense Aleutian Lows, above-average frequency of south-westerly winds and warmer coastal sea surface temperatures off the west coast of Vancouver Island(Ref#3). These favorable climate/ocean conditions (intensive Aleutian Low) increased the amount of food available (copepod nauplii) for sablefish larvae at depth resulting in production of a strong year class throughout the North Pacific (Ref#4, 5). Growth significantly enhanced by events of the El Nino-Southern Oscillation. Larval development and growth occur in much warmer water than that inhabited by later stages (ref#5). They are growing to a larger maximum size in more recent years(Ref#8). In comparison to other fish energetics studies, the sablefish grow very slowly and have very low food to flesh conversion efficiencies (Ref#13).								

ID	2	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		<i>Gadus</i>	<i>macrocephalus</i>	Pacific cod	Grey cod	18 yrs.	1m	
Species code		Indigenous name				Reproduction		Data update info
Economic species	Yes	Habitat notes				Females reach 50% maturity at 4.4 years in the Gulf of Alaska and Bering Sea		
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Mainly on the continental shelf and upper slopes. Eggs are deposited on or close to the bottom and				Feeding notes		
Species location	☐ Arctic ☒ SubArctic ☒ Bering Sea ☒ NPacific ☐ NWPac ☐ NEpac	Distribution and Abundance				Depth range	Depth preferred	Vulnerable life stage
		Distribution: Demersal and concentrate in the North Pacific and Bering Sea on the shelf edge and				10-550m	100-250 m in the winter and <100 m in	
Conservation status notes		Temperature optimum (Topt)		Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window	Spawning date	Vulnerable season
		Larvae = 1.3 to 6.7°C (sub-Arctic population) (Ref#3) Arval rearing: 4-6°C (Ref#6)			Growth rate = 11.5°C (Ref#4) Swim activity = 10-15°C (Ref#5)	Egg survival: (40% or greater) = 2-8°C (Ref#7)	late winter/spring	
		Topt (lat, long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	Justification provided ☐
				Sal_min	O2_min	pH_min	Other stressor2	Spp pic and refs compiled? ☒
Tcmax		Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies	Data quality check ☐
Adults: Mort at 20C two wks past Time 0 (Ref#4)		Eggs = 0C		Sal_error	O2_error	pH_error	Temp + Salinity (Ref#6). Salinity not a factor - temperature is (Ref#6)	
Eggs: Mort at								
Acclimation potential								
reproduction maturity plasticity (Ref#2)								
References								
#1. Carr et al., 1999; #2. Farley et al., 2016; #3. Copeman et al., 2017; #4. Laurel et al., 2016; #5. Doyle, 2016; #6. Bian et al., 2015; #7. Forrester and Alderdice, 1966; #8. Doyle et al., 2009; #9. Laurel et al., 2008; #10. Almatar, 1984; #11. Abookire et al., 2007; #12. Matarese et al., 1989; #13. Mecklenburg et al., 2002; #14. Hurst et al., 2009								
Data gap summary								
Notes								
Enhanced survival of Pacific cod larvae may occur during cold years (Ref#9.) Juvenile: Energetic status highest with cool sea temperature years linked to shift to high quality, lipid-rich prey found in greater abundance on the shelf and in the stomach contents of juvenile cod during cool years (Ref#2). NB: Growth is greater in warm years -thus growth not reliable indicator of survival. Eggs and larvae may have greater potential to be exposed to varying water masses (Ref#9). Spawning in the eastern Bering Sea is expected to take place within the period of January to April, when water temperature is higher than 0°C, the optimum temperature for hatching and survival is considered to be 5°C. Age and size at first maturity vary with areas, the southern stocks maturing at an earlier age. They are, respectively, for males and females: 2-3 years and 40 to 44 cm off Washington, 3 years and about 50 cm in the Gulf of Alaska and in the Bering Strait, and 5 years and about 67 cm off Rebun Island, Hokkaido.								

ID	3	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Clupea	pallasii	Pacific herring		19 yrs	46 cm (18 inches)	2017-11-15
Species code		Indigenous name				Reproduction		Data update info
Economic species	Yes	Habitat notes				The Pacific herring is a coastal schooling species. After hatching, herring larvae remain in warm		Added habitat notes
Fresh and/or saltwater	☐ FW ☒ SW ☐ Both	Feeding notes				Young: feed mainly on crustaceans, but also eat decapod and mollusk larvae;		
Species location	☒ Arctic ☒ SubArctic ☒ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance				Depth range	Depth preferred	Vulnerable life stage
		Distribution: Ranges from the northern Pacific Ocean into the Arctic Ocean. Southern BC is now				Surface to 3000 ft (910m)	Surface to 1,300 feet (400 m)	
		Temperature optimum (Topt)				Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window
		Larvae top condition = 6.85-11.5C Juvenile = 12.2C (Ref#13) Adult = 11.4C (Ref#13)						90% hatch: = 6.5-10.5C (Ref#12) Summer Growth:
Conservation status notes		Topt (lat long)				Respiration data	Sal_max	O2_max
							32ppm Embryo	
						Sal_min	O2_min	pH_min
						5ppm (Ref#12)		
		Heart rate data				Sal_opt	O2_opt	pH_opt
						90% hatch: 5		
						Sal_error	O2_error	pH_error
Acclimation potential		Eggs: high plasticity (Ref#12)				Multiple stress studies		
						Temperature + salinity.		
References		#1. Cleary et al., 2015; #2. Wailes, 1936; #3. Tanasichuk, 2012; #4. Tester 1948; #5. Ware 1991; #5. NOAA - fisheries #6. Pacific Herring Organization #7. Hershberger et al., 2013; #8. Griffin et al. 2004; #9 Raymon, 1989; #10 Schweigert, 1995; #11 Haist and Stocker, 1985; #12 Alderdice & Velsen, 1971; #13 Lassuy, 1989;						
Data gap summary		In the 1970's it was suggested that it would be of interest to compare, by similar criteria, the viability of Pacific herring eggs, incubated at temperatures between about 2 and 5C, from other regions over the range of geographic distribution (Ref#12). Still looking for publication of such a study.						
Notes		Adult: high VHAV 80% mort at 8.8C (Ref#7). Relationships between temperature and disease severity (VHAV) were likely explained by a kinetically faster innate immune response at warmer temps (Ref#7). Herring recruitment and survival has been linked to water temperatures (Ref#4, #5). In British Columbia, warmer temperatures cause a shift in herring's primary food: zooplankton. In particular, the composition of the plankton shifts from large lipid-rich northern species to smaller, less nutritious lipid-poor southern species. Warmer temperatures also cause southern predators such as Pacific mackerel and hake that feed on herring, to become more abundant (ref#6). Effects of temperature on egg development have been reported by McMynn and Hoar (1953), Outram (1955), and Taylor (1971) for eggs from British Columbia water but Alderdice & Velsen (1971) combine Temp and salinity of one sub-population from Ganges Harbour, which is the data used in this report.						

ID	4	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Pandalus	platyceros	Spot prawn	Spot shrimp	4 to 6 yrs. (Canada to C	Females ~ 23 cm (9 inch	
Species code		Indigenous name					Reproduction	Data update info
Economic species	yes	Habitat notes					Protandric hermaphroditic i.e. same life as males and	
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Rocky or hard bottoms including reefs, coral or glass-sponge beds. Juveniles concentrate in	Feeding notes				Spawning depth	
Species location	☐ Arctic ☐ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance	Depth range		Depth preferred		Spawning date	Vulnerable life stage
		Distribution: Related to temperature, salinity and habitat. Range from Aleutian islands to Sand Diego	Intertidal to 487m		Adults: 198-234m Juveniles: <90m		Late summer early autumn	Vulnerable season
		Temperature optimum (Topt)	Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window		Hatch date	Temperature limit
		Adults: (Strait of Georgia, B.C.) = 7 - 11°C and Larvae: from 0-13°C (Ref#3)	5C(Ref#3)	Egg development = 13 - 15°C	7-13C (Ref#1)		Spring	
Conservation status notes		Topt (lat. long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	
				35ppm	3.5 mg/litre (R			Justification provided ☐
				Sal_min	O2_min	pH_min	Other stressor2	Spp pic and refs compiled? ☒
				< 20ppm incre	0.5mg/l (Ref#			Data quality check ☐
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies		
Adult mort =21C (Ref#1)	3C(Ref#4)		30ppm (Ref#2)					
Larvae 85% mort =15.2C (Ref#3)			Sal_error	O2_error	pH_error			
			Prawns are r	Depends on sa				
Acclimation potential								
References								
	#1. Bergstrom, 2000; #2. Quarmby, 1985; #3. King, MSc Thesis - Memorial University, 1997 #4 Whyte and Carswell, 1982;							
Data gap summary								
Notes	More review needed. Crustacean physiology expert - contact Dr. Denis Chabot. Denis.Chabot@dfo-mpo.gc.ca							

ID	S	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Panope	generosa	Pacific geoduck	Panope abrupta (Ref#3)	140-168 yrs. (Ref#2)	20cm with 1 m siphon -	2018-12-02
Species code		Indigenous name					Reproduction	Data update info
Economic species	Yes	Habitat notes					3 yr maturity (Ref#4) Simple annual	Species location
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Burial in up to 1m of mud and sand in lower intertidal and subtidal. Clumping of juveniles near		Feeding notes			Spawning depth	Vulnerable life stage
Species location	☐ Arctic ☐ SubArctic ☐ Bering Sea ☒ NPacific ☒ NWPac ☐ NEpac	Distribution and Abundance		Depth range		Depth preferred	Spawning date	Vulnerable season
		Distribution: (58N-34N) Along the west coast intertidal of North America from Alaska to Baja (Ref#15)		Lower intertidal to 110m (Ref#4)			March - July (Ref#8,9,10,25, 26)	
		Temperature optimum (Topt)		Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window	Hatch date	Temperature limit
		Spawning: 12-14C (Ref #11) Broodstock conditioning = 11C (Ref#15)		Spawn trigger temp = 8.5C (Ref#15)	Health declined = 19C (Ref#16)	Spawning: Triggered at 8.5 - 12C (Ref#4, 11, 15)	16-35 days at 16C (Ref#4)	
Conservation status notes		Topt (lat, long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	Justification provided ☐
				32.5 ppt (Ref#)				
				Sal_min	O2_min	pH_min	Other stressor2	Spp pic and refs compiled? ☒
				27.5 ppt (Ref#)				Data quality check ☐
Tcmax		Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies	
Gonads degenerated = 19C (Ref#15)		low spawning activity = 7C (Ref#15)					Known to be sensitive to temp, salinity (see Ref#12, #13) but also pH (aragonite shell particularly sensitive - Ref#14)	
Adult mortality = 18C (Ref#25) Adults		Adults:		Sal_error	O2_error	pH_error		
Acclimation potential		The ability to acclimate to a wide range of temperatures is typical of temperate marine bivalves (Ref#17-#21)						
References	#1. Straus et al., 2009; #2. Orensanz et al., 2004; #3. Vadopalas et al., 2010; #4. Goodwin & Pease, US Army Corps biological report 82(11.120), 1989; #5. Fyfe, 1984; #6. Noakes and Campbell, 1992; #7. Cerrato, 2000; #8. Andersen, 1971; #9. Goodwin, 1976; #10. Sloan and Robinson, 1984; #11. Goodwin, 1979; #12. Goodwin, 1973; #13. Lough, 1975; #14. Orr, 2009; #15. Marshall et al., 2012; #16. Feder et al., 1979; #17. Bayne and Newell, 1983; #18. Chávez-Villalba et al., 2003; Ref#20. Mann, 1979; #21. Navarro et al., 2000; #22. Arney et al., 2015; #23. McDonald et al., 2015 #24. Washington Dept of Fisheries & Washington Department of Natural Resources, 1985; #25. Goodwin, 1976; #26. Campbell & Ming, 2003;							
Data gap summary	Missing: migration potential + pH sensitivity + cold tolerance. Both larval development and adult growth is tied to temperature (Ref #1). Increasing temperature may extend the northern range of geoduck clams into waters that were previously too cold to support a significant fishery (Ref#13).							
Notes	The optimal water temperature and salinity for the development of geoduck clam larvae increases as larvae transition from embryonic stages to planktonic larvae (Ref#13). Future investigations are required to establish the upper thermal limit of British Columbia geoduck juveniles and adults (Ref#22)							

BD	6	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Sebastes	olutus	Pacific Ocean perch (PO)		100yrs (#11)	53cm	
Species code		Indigenous name					Reproduction	Data update info
Economic species	Yes	Habitat notes	Demersal shelf rockfish (Ref#7). Larvae: preferred nearshore habitat consists of rough substrata and				Mature beginning at 5-7 yr upwelling-	
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Feeding notes	Feed on a range of organisms, from zooplankton to fish (Ref#9)				Spawning depth	
Species location	☐ Arctic ☐ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance	Distribution: POP inhabit demersal shelf and slope habitat throughout the North Pacific, but catches				Depth range	Depth preferred
		Temperature optimum (Topt)	Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window		Spawning date	Vulnerable life stage
		Juveniles & adults: abundance highest = 4.5 - 5.0C (over depths of 200 - 250 m) (Ref#7)	5C (Ref#13)		3-7C (Ref#7) 4.8C - 6.7C (Ref#10)		Hatch date	Temperature limit
Conservation status notes		Respiration data	Sal_max	O2_max	pH_max	Other stressor1	Parturition occurs during April and	
		Sal_min	O2_min	pH_min	Other stressor2	Justification provided		
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies	Spp pic and refs compiled?	
9 SC(Ref#13)			Sal_error	O2_error	pH_error		Data quality check	
Acclimation potential								
References	#1. Carlson & Haight, 1976; #2. Allen and Smith, 1988; #3. Gunderson, 1971; #4. Palofet et al., 2011; #5. Kamin et al., 2013; #6. Rooper et al., 2007; #7. Laman et al., 2015; #8 Rooper, 2008; #9. Love et al., 2002; #10. Scott, 1995; #11. Beamish, 1979; #12 Lyubimova, 1964; #13. Snytko 1971							
Data gap summary								
Notes								

ID	7	Genus	Species		Common name (1)	Common name (2)	Life span estimate	Max length	Data update date	
		Atheresthes	stomias		Arrowtooth flounder	Turbot	27yrs	86cm		
Species code		Indigenous name				Reproduction		Data update info		
Economic species	Yes	Habitat notes								
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Coastal waters along the Alaska Peninsula are NOT a primary nursery habitat (Ref#2).		Feeding notes		Young five to 12 millimeters long feed primarily on copepods and their nauplii, as well as		Spawning depth		
Species location	☐ Arctic ☒ SubArctic ☒ Bering Sea ☒ NPacific ☒ NWPac ☒ NEPac	Distribution and Abundance		Depth range		Depth preferred		Vulnerable life stage		
		Distribution: Bering Sea to California Deep water species. Abundance: Dramatically increased in		Adults > 100 m (Ref#2)		Eggs: > 400m (Ref#3) Adults: 274 to 472 m		Deep water spawning (Ref#3)		
		Temperature optimum (Topt)		Tmin (or Tpejus)		Tmax (or Tpejus)		Spawning date		
		Spawning 3-1C (Ref#3)				Spawning: 4.3 - 5.4C (Ref#3)		mid- to late winter		
		Tmin (or Tpejus)		Tmax (or Tpejus)		Topt window		Hatch date		
								Temperature limit		
Conservation status notes		Topt (lat, long)		Respiration data		Sal_max		O2_max		
						pH_max		Other stressor1		
						Sal_min		O2_min		
						pH_min		Other stressor2		
Tcmax		Tcmin	Heart rate data		Sal_opt		O2_opt		pH_opt	
Egg development 6-2C (Ref#3)		Eggs: 5-1C mort (Ref#3)			Sal_error		O2_error		pH_error	
Acclimation potential										
References										
	#1. McLem & Delaney, 1977; #2. Hurst, 2016; #3. Blood et al., 2007; #4.									
Data gap summary										
Notes	Cheung, W.L., R. Watson and D. Pauly, 2013. Signature of ocean warming in global fisheries catch. Nature 497: 365-368. Published temperature limit of 9C based on sea surface temperature at specific lat/long. The relative recruitment into Bering Sea of arrowtooth flounder (and rock sole and flathead sole) was high in 1977 to 1988 (NB: AO neg, high pressure, SW wind) and low in 1988 to 1998 (AO pos, low pressure, SE winds), indicating a link between surface wind advection patterns during the larval stage and flatfish survival (Ref - ACIA report- 2005). Note for Ref#1. McLem & Delaney, 1977 (see https://www.gpo.gov/fdsys/pkg/CZIC-sh327-5-f65-1977-v-2/html/CZIC-sh327-5-f65-1977-v-2.htm)									

ID	9	Genus	Species		Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
Species code		<i>Squalus</i>	suckleyi		Pacific spiny dogfish	Mud shark	100 yr.		
Economic species	Yes	Indigenous name					Reproduction	Data update info	
Fresh and/or saltwater	☐ FW ☒ SW ☐ Both	Habitat notes					Internal fert & vivoviparous		
Species location	☐ Arctic ☐ SubArctic ☒ Bering Sea ☒ NPacific ☐ NWPac ☒ NEPac	Distribution and Abundance					Feeding notes	Spawning depth	Vulnerable life stage
		Seasonal north south migrations(Ref#5). Marine - brackish - benthopelagic (Ref#1). Mobile but					Transitory meso-opportunistic predators - generalist diet(Ref#7)		
		North Pacific: Korea, Japan, northward to Russia (Kamchatka, Sea of Okhotsk and Sakhalin), the					Depth range	Depth preferred	Spawning date
							Surface to 1,236+m(Ref#2)	15 - 110 m (Ref#2)	Parturition = Sept - Jan in SOG(Ref#5)
		Temperature optimum (Topt)					Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window
		8 to 12C (Ref#3)							7- 15C (Ref#4, #2)
		[8-9C winter/spring](Ref#3)							They follow this temp
		[10-12C summer/autumn] (Ref#3)							
Conservation status notes		Topt (lat_long)					Sal_max	O2_max	pH_max
		Respiration data					Sal_min	O2_min	pH_min
Tcmax		Tcmin	Heart rate data					Sal_opt	O2_opt
								Sal_error	O2_error
Acclimation potential							pH_opt		Other stressor1
									Other stressor2
Feeding rates were lower than those found for individuals in the California Current range: 0.351 to 0.407(Ref#8)									
References									
#1. Fish Base; #2. Ebert et al., 2010; #3. NOAA 1990 #4. Andrews and Harvey, 2013; #5. Jones & Geen, 1977; #6. Penaluna & Bodensteiner 2015; #7. Reum and Essington, 2008; #8. Harvey, 2009; #9. Hopkins & Cech, 2003;									
Data gap summary									
temperature and salinity have been shown to affect the distribution and abundance of elasmobranchs (Ref#9). Yet to date have found no T45 study for this species.									
Notes									
This species is closely related to <i>Squalus acanthias</i> and for many years they were treated as a single species. In Puget Sound, there appears to be a correlation between mean temperature and the proportion of tagged dogfish returning to Puget Sound each year (Ref#4). However, seasonal differences in water conditions cannot account for the different large-scale patterns observed between mature and immature individuals.									

ID: 13	Genus: <i>Merluccius</i>	Species: <i>productus</i>	Common name (1): Pacific hake	Common name (2): Pacific whiting	Life span estimate: 20yrs	Max length: 81cm max but most co	Data update date:
Species code:	Indigenous name:		Reproduction: Mature 2yrs. (41%) and full maturity at 5yrs.		Data update info:		
Economic species: Yes	Habitat notes: The northern tip of Vancouver Island is the northern limit of hake aggregations. They range		Feeding notes: Euphausiids are the most important food item but also feed on herring - impact herring		Spawning depth: Adults: 130-500m; Eggs: 40-60m float up		
Fresh and/or saltwater: ☒ SW ☐ Both ☐ Brackish	Distribution and Abundance: Distribution: From 25N to 55N. This stock exhibits seasonal migratory behavior. Associated with		Depth range: Up to 900m (3,000 ft.)		Depth preferred: 50-500m; Eggs: 40-60m (Ref#11)		Vulnerable life stage:
Species location: ☐ Arctic ☐ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Temperature optimum (Topt): Eggs: 10.2-11.3(Ref#3); Adults: 11C(Ref#1)		Tmin (or Tpejus): 9C(Ref#14)		Tmax (or Tupejus): 15C(Ref#14)		Spawning date: Winter
Conservation status notes:	Topt window: 9-15C		Hatch date: Jan - Feb (80%) California Peak in		Temperature limit:		
Topt (lat, long):		Respiration data:	Sal_max:	O2_max:	pH_max:	Other stressor1:	Justification provided: ☐
Tcmax:		Tcmin:	Sal_min:	O2_min:	pH_min:	Other stressor2:	Spp pic and refs compiled? ☒
Heart rate data:		Sal_opt:	O2_opt:	pH_opt:	Multiple stress studies:		
Adult = 17 SC (Ref#1) Egg hatching = 14C (Ref#11)		Adult = 3 SC(Ref#1) Egg hatching = 11C (Ref#11)	Sal_error:	O2_error:	pH_error:	Data quality check: ☐	
Acclimation potential:							
References:							
#1. Agostini et al., 2006; #2. Dorn, 1995; #3. Moser et al., 1997; #4. Ware and McFarlane, 1995; #5. Benson et al., 2002; #6. Berger et al., 2017; #7. Perry. Canadian Climate Forum, 2015; #8. Benson, MSc Thesis, 2002; #9. Benson et al., 2002; #10. Hodgson et al., 2016; #11. Baily and Stevens, 1982; #12. Zweifel & Lasker, 1976; #13. Saunders & McFarlane, 1996; #14. http://www.nmfs.noaa.gov/pr/species/fish/pacific-hake.html , 2015							
Data gap summary:							
There are many research projects that could improve the stock assessment for Pacific Hake. To fully explore any change in hake distribution, information on the availability and (or) abundance of euphausiids is required (Ref#9). The following priority topics will lead to improved biological understanding and decision making: 1. Basic physiology particularly for							
Notes:							
In years with warmer water the stock tends to move farther to the north during the summer e.g. 2015(Ref#6). The location of the apparent northern front of spawning is correlated to the sea surface temperature (Ref#11). Egg hatching is temperature dependent (Ref#11). Since 1994, the hake have been spawning off the west coast of Vancouver Island (Ref#13). Juveniles reside in shallow coastal waters, bays, and estuaries (Ref#14). Distinct offshore and coastal populations (max size, fecundity, genetic). Larger and mature later in Northern range(Ref#14). Pacific hake were one of the first fish species to occur in Saanich Inlet following glacial retreat from the region, after approximately 12,000 years before present (BP). Fish abundance and species diversity peaked in Saanich Inlet between 7,500 and 6,000 BP, and the last 1,000 years have seen some of the lowest abundances of fishes in Saanich Inlet's marine history. The close proximity of Saanich Inlet to Puget Sound would suggest that Pacific hake were also likely established in Puget Sound by about 12,000 BP.							

ID	14	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Boreogadus	sassa	Polar cod (Europe)	Arctic cod (North Ameri)	7yrs	40cmTL	2017-11-15
Species code		Indigenous name	Inuktitut (I): Qiga, Qiga, Qvix, Equahag, Roik, Qigark, Uugaq Inuvialuktun (In): Uqavik			Reproduction	Data update info	
Economic species	Yes	Habitat notes	Cryopelagic, swarm during ice break up around coastal areas (1-yr olds) Larvae and juvenile live			Feeding notes	2-yr maturity males develop gonads in summer, females in fall	
Fresh and/or saltwater	☐ FW ☒ SW ☐ Both	Distribution and Abundance	Pan Arctic distribution - no definitive population DNA differences (Ref#16). Bering Sea(Ref#18)			Depth range	Depth preferred	Vulnerable life stage
Species location	☒ Arctic ☒ SubArctic ☐ Bering Sea ☐ NPacific ☐ NW Pac ☐ NE Pac	Temperature optimum (Topt)	Tmin (or Tlpejus)	Tmax (or Tpejus)	Topt window	Spawning date	Vulnerable season	
		Larvae (acclimation 3.5C) = 3.3C (Ref#2)	Acclimation 0.5C = 0.2C	Eggs = 3.5C (Ref #2) Larvae = 7.6C (Ref#2)	Reproduction -1.4 to 3.5C(Ref#7, #23)	Winter under ice	Summer	
Observation status notes		Adults (acclimation 0.5C) = 1.0C	Acclimation 3.5C =	Adults Heart rate:	Batch date	Temperature limit		
		Top1 (let long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	
		n/ap - Lab study	Adults@ BMR: Acclimation 0.5C = Acclimation 3.5C =	Sal_min	O2_min	pH_min	Other stressor2	
		Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies
		1.4C(Ref#23)	Adults: TAB Acclimation 0C = 3.6C Acclimation 3.5C = 4.7C Acclimation 6.5C = 4.3C	Sal_error	O2_error	pH_error	Data quality check	
		Acclimation potential	Yes using Tcmax = 0.43 slope increase for every 1C increase in acclimation temp (from 1 to 6.5C) (Ref#3)					
		References	#1. Drost, 2014; #2. Drost, 2015; #3. Drost, 2016; #4. Kunz, 2016; #5. Crawford et al., 2010; #6. Davis et al., 2016; #7. Kent et al., 2016; #8. Majewski et al., 2015; #9. Leo et al., 2017; #10. Harwood et al., 2015; #11. Andriyashov et al., 1980; #12. Craig et al., 1982; #13. Moulton and Tarbox, 1987; #14. Gradinger & Bluhm, 2004; #15. Majewski et al., 2013; #16. Nelson et al., 2013; #17. Fishbase.org; #18. Short et al., 2006; #19. Laurel et al., 2015; #20. Kent et al., 2016; #21. Coad & Reist, 2018; #22. Kuhn et al., 2018; #23. Hop & Tonn, 1998; #24. Villa et al., 2016;					
		Data gap summary	No multiple stress studies have been conducted on eggs, larva but a few studies have included Temp + OA for adults using growth and mitochondrial leaking to quantify impact (Ref#4, 9). A few interesting species comparative studies (with Caplin primarily) but more need to be conducted with additional indicators of performance.					
		Notes	Fisheries: highly commercial (Ref#17). High load of perfluorooctane sulfonate (PFOS) found in Arctic cod (Ref#24) as well as microplastic (Ref#22). A suite of respiratory and heart rate sub-chronic and chronic transition temperatures (i.e. a Fry Polygon) are not entered in database (space limitation). See Ref#3 for details.					

ID	15	Genus	Salvelinus	Species	alpinus	Common name (1)	Arctic charr	Common name (2)		Life span estimate	Western 15yr and Eastern	Max length	Western 660mm FL	Data update date	2017-11-27	
Species code		Indigenous name	Qalukpak, Evitaruk for both Dolly Varden and Arctic Charr, Qalvaqpak, Qkalukpak refer to land-locked charr (in)				Reproduction	Mature between 5-12 yrs. Spawn in quiet			Data update info	Added thermal limits				
Economic species	Yes	Habitat notes	Anadromous and nonanadromous (landlocked) populations, the former migrating to				Feeding notes	Opportunistic feeder(Ref#9). Eat predominately amphipods, isopods, mysids, and fish (Ref#4, #5)			Spawning depth	Eggs are buried in a nest on the				
Fresh and/or saltwater	☐ SW ☒ Both ☐ Brackish	Distribution and Abundance	Circumpolar lakes & some also marine. In eastern Canada, the Arctic charr is found in many lakes, but				Depth range	6-120m(Ref#7)		Depth preferred	30-70m(Ref#7)		Spawning date	Late August, Sept. And peaks early Oct. (Ref#7)		
Species location	☒ Arctic ☐ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEpac	Temperature optimum (Topt)	Adults = 7.5C(Ref#6) Growth = 12C(Ref#21)		Tmin (or Ticejus)	Eggs < 3C (Ref#14)		Tmax (or Ticejus)	Adults = 16C(Ref#2) Adults Growth(max) freshwater = 15.1C (Ref#14, #15)		Topt window	Adults = -0.6 to 19.1C (Ref#6) Hatching: 5-16C(Ref#14)		Hatch date	April - May	
Conservation status notes	Subsistence species															
Top (lat long)	Respiration data		Sol_max		O2_max		pH_max		Other stressor1		Justification provided ☐					
lab study			Sol_min		O2_min		pH_min		Other stressor2		Spp pic and refs compiled? ☒					
Tcmax	Tcmin		Heart rate data		Sol_opt		O2_opt		pH_opt		Multiple stress studies					
larvae = 22C	Adults = 0C (Ref#2)		Adults: TAB = 7.5C ± 0.4 (Ref#6)		80% sat (Ref#)		CO2 = 10-20m		CO2 + oxygen(Ref#17)							
feeding(Ref#20)Alevins, fry and parr (acclimation 5C) =	Parr & fry <1C(Ref#18)		Adults: Tmax@ Acclimation 10C = 23C		Sol_error		O2_error		pH_error							
Alvins <0.3C(Ref#18)																
Acclimation potential	negligible geographical variation in the thermal limits of Arctic charr (Ref#19)															
References	#1. Penney et al., 2014; #2. Quinn et al., 2011; #3. Johnson and Burns, 1984; #4. McCart, 1980; #5. Stewart and Sparling, 1987; #6. Hansen et al., 2016; #7. EOL.org; #8. Page and Burr, 1991; #9. Scott & Crossman, 1973; #10. Patnaik et al., 1994; #11. Lyytikäinen et al., 1997; #12. Gilbert et al., 2016; #13. Elliott & Elliott, 2010; #14. Jeuthe et al., 2017; #15. www.troutlodge.com; #16. Gyselman, 1984; #17. Musa, 2013; #18. Barody & Elliott, 1994; #19. Elliott & Klemetsen, 2002; #20. Thyrel et al., 1999; #21. www.fsl.orst.edu/~johnsons/AppdxA.pdf															
Data gap summary																
Notes	During the summer anadromous Arctic charr can undertake marine migrations of over 500 km and do not always return to overwinter in their natal river systems (Ref#16). Temperature tolerance for alevins is slightly lower than that for parr and smolts, and the eggs have the lowest tolerance; this being the most vulnerable life stage to any temperature increase, especially for eggs of <i>S. alpinus</i> in shallow water (Ref#13.)															

ID	33	Genus	Species		Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Mallotus	villosus		Capelin	Barents Sea capelin	10yrs(Ref#1) Nfoundian	25cm(female), 20cm(m)	2017-11-27
Species code		Indigenous name	Amagiak, Agmagiak, Axmagiaq, Angmaggeuck, Kurdhiliyak, Qulilraq, Nullilghuk, Holli-gah, Qolilgaq (I).		Reproduction		Data update info		
Economic species	Yes	Habitat notes	Nerito-pelagic(Ref#2). Capelin overwinter in offshore waters.		Feeding notes		Two modes of reproductive		
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Distribution and Abundance	Circumpolar in distribution and found in the Northern regions of the Atlantic and Pacific oceans.		Depth range		Depth preferred		Spawning depth
Species location	☒ Arctic ☒ SubArctic ☒ Bering Sea ☒ NPacific ☐ NWPac ☐ NEpac	Temperature optimum (Topt)	Tmin (or Tpejus)	Tmax (or Tupejus)	Topt window		Spawning date		Vulnerable life stage
		Spawning: 2.5-10.8C(Ref#6) Spawning (NL coastal) 3.5-10C (Ref#4) Egg-hatching: 1-19C(Ref#6)	0C(Ref#12)	14C(Ref#4, #10)10C(Ref#6)	-1-6C(Ref#4) -0.5C-8.5C(Ref#6)		May-July		Vulnerable season
Conservation status notes		Topi (lat, long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1		Temperature limit
		Newfoundla and region		Sal_min	O2_min	pH_min	Other stressor2		Justification provided ☐
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies		Spp pic and refs compiled? ☒	Data quality check ☐
	-1.5C(Ref#4)		Sal_error	O2_error	pH_error				
Acclimation potential									
References	#1. eol.org; #2. Allen and Smith, 1988; #3. Naumenko, 1996; #4. Rose, 2005; #5. Froese and Pauly, 2006; #6. Rose and Leggett, 1990; #7. Fortier and Leggett, 1985; #8. Anderson et al., 2002; #9. www.geog.mcgill.ca/climatechange; #10. Shackell et al., 2013; #11. Rose & Leggett, 2011; #12. Methven & Platt, 1991; #13.								
Data gap summary									
Notes	Capelin ranked as one of the more sensitive fishes to climate change because of the immobility of its demersal eggs, the stenothermal nature of the species, and its comparatively northern distribution. The most sensitive stages of capelin to higher temperatures resulting from global warming likely are the incubating embryos and pre-emerged, yolk-sac larvae living in beach sediments. (Ref#9)								

ID	35	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Hippoglossus	stenolepis	Pacific halibut		55yrs	2.4m	2018-05-03
Species code		Indigenous name					Reproduction	Data update info
							Males 8yr, females 12yr	Life history
Economic species	Yes	Habitat notes					Feeding notes	
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Demersal, living on or near the bottom of the water					Opportunistic feeders and larger fish can leave the bottom to feed on cod, sablefish, pollock.	Spawning depth
Species location	☐ Arctic ☒ SubArctic ☐ Bering Sea ☒ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance					Depth range	Depth preferred
		Found on the continental shelf of the North Pacific Ocean and Bering Sea. Predominantly clockwise					Surface to 500m summer feeding and	eggs = 100-200m larvae = surface
Conservation status notes		Temperature optimum (Topt)		Tmin (or Topejus)	Tmax (or Topejus)	Topt window	Spawning date	Vulnerable life stage
					eggs = 8C (Ref#2) adults = 12-14C (Ref#2)	Adults: 3-8C (Ref#1)	November to March (Ref#1)	juveniles
		Topt (lat long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	Vulnerable season
				Sal_min	O2_min	pH_min	Other stressor2	May/June at surface t
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies	Justification provided	Spp pic and refs compiled?
			Sal_error	O2_error	pH_error			Data quality check
Acclimation potential								
References	#1. IPHC Technical Report No. 40, 1998; #2. International Halibut Commission report; #3.							
Data gap summary								
Notes	Fish industry note that Chalkiness in fish flesh probably due to higher water temperature (see International Pacific Halibut Commission)							

ID	39	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Calanus	glacialis	copepod		2-3yrs	3.5-5.2 mm total length	2017-11-21
Species code		Indigenous name						Reproduction
Economic species		Habitat notes						Data update info
Fresh and/or saltwater	☒ SW ☐ Both ☐ Brackish	Most abundant on shelf areas deeper than 50 m, commonly advected off shelves into deep basins						Spawn based on lipid reserve clutch size max 100 eggs
Species location	☒ Arctic ☐ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance						Spawning depth
		This important pelagic species can comprise up to 70-80% of the						Surface waters
		Depth range						Vulnerable life stage
		Concentrated in surface waters during						Spawning date
		Temperature optimum (Topt)						Spring - summer
		Tmin (or Ticejus)						Vulnerable season
		Tmax (or Tupejus)						Match date
		Topt window						Temperature limit
		10C (Ref#6) 5C with 3000 uatm (Ref#6)						Late copepodites (CIII-CVI) overwinter at
Conservation status notes		Topt (lat_long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	
				Sal_min	O2_min	pH_min	Other stressor2	Justification provided ☐
						Adult: 6.9 pH		Spp pic and rels compiled? ☒
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies		
			Sal_error	O2_error	pH_error	Temp + OA		
Acclimation potential								
References	#1. Weydmann et al., 2012; #2. Blachowiak-Samolyk et al., 2008; #3. Conover, 1988; #4. Hirche and Mumm, 1992; #5. Thor et al., 2017; #6. Hildebrandt et al., 2014;							
Data gap summary								
Notes	Interestingly, these effects were not observed in stage CV copepodites from any of the three locations. It seems that CVs may be more tolerant to OA perhaps due to a general physiological reorganisation to meet low intracellular pH during hibernation							

ID	51	Genus	Species	Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Limacina	helicina	Pteropod		1yr arctic, 2yr subarctic		
Species code		Indigenous name					Reproduction	Data update info
							Protandrous hermaphrodite (males)	
Economic species	No	Habitat notes					Spawning depth	
Fresh and/or saltwater	☐ FW ☐ SW ☐ Both	Strictly pelagic	Feeding notes Eats copepods. Is a critical food source for fish and other key species. It forms the main food of					
Species location	☒ Arctic ☒ SubArctic ☐ Bering Sea ☒ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance	Depth range		Depth preferred		Spawning date	Vulnerable life stage
		Polar (interesting evolution. L. helicina was formerly believed to have a bipolar distribution.	Up to 1,800m				Early spring	Vulnerable season
Conservation status notes		Temperature optimum (Topt)	Tmin (or Tlpejus)	Tmax (or Tupejus)	Topt window		Hatch date	Temperature limit
key food web species		-0.4C to 4C (Ref#1)		7C (Ref#2)	-0.4C rarely up to 7C (Ref#1)			
		Topt (lat, long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	
				35.1PPS(Ref#)	9.3ml/l			Justification provided ☐
				Sal_min	O2_min	pH_min	Other stressor2	Spp pic and refs compiled? ☒
				22.2PPS(Ref#)	0.5ml/l	Q ~ 0.8 = seve		Data quality check ☐
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies		
1C 5C(Ref#1)	-1.9C(Ref#1)		Sal_error	O2_error	pH_error	Routine oxygen consumption rates and the metabolic response [oxygen consumption (MO2), ammonia excretion (NH3), overall metabolic balance (O N)] to elevated levels of pCO2 and		
Acclimation potential								
References								
	#1. http://eol.org/pages/453422 ; #2. http://species-identification.org ; #3. Comeau et al., 2009; #4. Haigh et al., 2015; #5. Bednaršek, 2012							
Data gap summary								
Notes	evidence of dissolution when harvested from waters under, or near, saturation with respect to aragonite(Ref#4)							

ID	S4	Genus	Species		Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Spisula	polynyma		Surf clam	Mactromeris polynyma	13-14yrs	Shell lengths between 2	
Species code		Indigenous name					Reproduction	Data update info	
Economic species	Yes	Habitat notes					Feeding notes		
Fresh and/or saltwater	☐ FW ☐ SW ☐ Both						Preyed upon by gastropods, sea stars, and also by sea otters	Spawning depth	
Species location	☒ Arctic ☒ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance					Depth range	Depth preferred	Vulnerable life stage
		Arctic Seas, from Rhode Island (western Atlantic) to Alaska and Puget Sound (east Pacific). Also in Japan					0-168m (Ref#1,2)		Spawning date
		Temperature optimum (Topt)		Tmin (or Tlpejus)		Tmax (or Tupejus)		Topt window	Vulnerable season
Conservation status notes		Topt (lat, long)		Respiration data		Sal_max	O2_max	pH_max	Other stressor1
						32.78PSU(Ref	103.4%sat(7.3		See Ref#2 for nitrate, silicate,
						Sal_min	O2_min	pH_min	Other stressor2
						31.2PSU	87.9%sat(5.67		Justification provided ☐
Tcmax		Tcmin	Heart rate data			Sal_opt	O2_opt	pH_opt	Multiple stress studies
9.68C(Ref#2)		1.87C(Ref#2)				Sal_error	O2_error	pH_error	Spp pic and refs compiled? ☒
									Data quality check ☐
Acclimation potential									
References									
	#1. FAO fact sheet - http://www.fao.org ; #2. EOL.org/pages/395979/data; #3.								
Data gap summary									
Notes									

ID	87	Genus	Species		Common name (1)	Common name (2)	Life span estimate	Max length	Data update date
		Gadus	morhua		Atlantic cod	bank cod	25yrs	~130cm	2018-02-15
Species code		Indigenous name					Reproduction	Data update info	
Economic species	Yes	Habitat notes		Feeding notes			Mature from 3 (coastal) to 8-12yrs old	Multiple stress study	
Fresh and/or saltwater	☐ FW ☒ SW ☐ Both	Adult cod live near the ocean floor along rocky slopes and ledges. Eggs, larvae, and early juveniles		Omnivorous. Bottom feeders, fish, worms, crabs, shrimp, prawns, young cod			Spawning depth		
Species location	☐ Arctic ☒ SubArctic ☐ Bering Sea ☐ NPacific ☐ NWPac ☐ NEPac	Distribution and Abundance		Depth range	Depth preferred	Bottom of continental shelf		Vulnerable life stage	
		Found on both sides of the Atlantic Ocean. In the Northwest Atlantic, cod range from Greenland to		Surface - 600m	Juvs (10-30m) Adults (10-150m)	Spawning date		Planktonic larval stag	
		Temperature optimum (Topt)		Tmin (or Tpejus)	Tmax (or Tupejus)	Topt window	Nov-June but mostly Jan-April	Vulnerable season	
		3C(Ref#1) 8.5-8.8C larvae optimum survival (Ref#9)		0C(Ref#1) -0.5C(Ref#4)	Adults = 13C (Ref#1) Spawning = 9C (Ref#2)	3-7C(Ref#1)adult 0-5C(Ref#2)adult 0-6C(Ref#10)adult	Hatch date	Temperature limit	
Conservation status notes	Vulnerable/some stocks considered endangered	Topt (lat_long)	Respiration data	Sal_max	O2_max	pH_max	Other stressor1	Significant tiss	
				Sal_min	O2_min	pH_min	Other stressor2	Justification provided ☒	
Tcmax	Tcmin	Heart rate data	Sal_opt	O2_opt	pH_opt	Multiple stress studies		Spp pic and refs compiled? ☒	
19C(Ref#5) 8C Spawning(Ref#5) 12-15C Eggs (Ref#8) 16C larvae growth	-1.5C(Ref#5) 1C Spawning (Ref#5) 4C larvae (Ref#7)		Sal_error	O2_error	pH_error	With temperature and hypoxic stress fish would prefer colder water (8-10C) with only 15% and 20% saturation respectively (Ref#11)		Data quality check ☐	
Acclimation potential									
References	#1. Shackell et al., 2013; #2. Rose & Leggett, 2011; #3. Frommel et al., 2012; #4. Claireaux et al., 1995; #5. Righton et al., 2010; #6. Jobling, 1988; #7. Laurence, 1978; #8. Iversen & Danielsen, 1984; #9. Otterlei et al., 1999; #10. Hardy, 1978; #11. Schurmann and Steffensen, 1992.								
Data gap summary	Heart rate and respiration data are available but do not look specifically at temperature limits								
Notes	Reduced to less than 10% of their original biomass mostly because of overfishing. They are considered mild to moderately sensitive to global warming.								